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ABSTRACT

This manual on repair of major appliances is one of a series of individualized instructional materials for students. The manual is self-paced, but is designed to be used under the supervision of a coordinator or an instructor. The manual contains 36 assignments, each with all the information needed, a list of objectives that should be met, and exercise questions that can help in meeting those objectives. The assignments are organized into 12 sections that cover the following topics: introduction to major appliance repair; safety; hand tools; power tools; electrical and magnetic fundamentals; controls; electromagnetic fundamentals of AC generators, transformers, and motors; theory and measurement of alternating current; electrical meters and test equipment; heating and lighting; electric appliances; and gas appliances. A glossary is included in the manual. (KC)

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Major Appliance Repairer

D.O.T. 723.381-010
T.E.A. 17.02 00

Student's Manual

By
Bill Bacon and Mack Sutton

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Editor / Barbara S. Lankes
Art Director / Ben E. Smith
Artist / Denise Sanderson
Publications Manager / James L. Cockrum
Curriculum Specialist / L. A. Grimes, Jr.
Coordinator Development / Jim Zukowski, Ed.D.

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Foreword

This publication is one of a series of individualized instructional materials. Students using this material can work at their own pace, enabling them to concentrate on areas that best fit specific needs. The design of the instruction makes it possible to relate work experience with materials studied at school.

Although the material is designed for individualized study, it should be used under the supervision of an instructor. For that reason, two basic publications are offered—a student's manual and an instructor's guide.

The *student's manual* is for the use of the person in training. The assignments is this manual are self-contained. Each assignment has a list of objectives and exercise questions that can help the student meet those objectives.

The *instructor's guide* has additional information that may help the instructor help the student. There are suggestions on how the student should use the student's manual, and how the instructor can coordinate work experience and learning in school. The instructor's guide also contains (1) answers to exercise questions and assignment test questions, (2) one set of assignment tests, (3) a progress record, and (4) work sheets that the instructor can use to relate instruction to job experience for the student.

Although both publications are copyrighted, an instructor should feel free to reproduce copies of the assignment tests, progress record, and work sheets. To make that possible, these have been placed in a separate section of the instructor's guide, where they are accessible for copying. If the instructor prefers, copies of these same sheets can be ordered separately for individual students from Extension Instruction and Materials Center, The University of Texas at Austin, P.O. Box 7218, Austin, Texas 78712.

Jack E. Robertson, Ph.D.
Director, Extension Instruction
and Materials Center

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A Special Note to the Student

The assignments in this manual are designed to help you learn. You will gain more from this material if you know how to work the assignments. For that reason, Assignment A-1 is about how to use this manual and should be completed first.

Section

A

Introduction to Major Appliance Repair

A-1. Using This Manual
A-2. Occupation Outlook for Appliance Repairers

A-1

Using This Manual

Objectives: After completing this assignment, you will be able to—

1. state the purpose of a student's manual;
2. discuss the reasons for the assignment objectives;
3. discuss the procedure to use when studying the information part of an assignment;
4. discuss the uses of the assignment exercises; and
5. tell how the assignment tests are used.

Purpose of a Student's Manual

A student's manual is designed to present technical instructions, procedures, and illustrations to groups of trade and industrial students. It may also be used by other groups in which the learning levels of individual students vary considerably. It is not intended to be used as a correspondence course, but must be used by students under the direct supervision of an instructor.

Information in the student's manual is designed to be read at about the same time that related operations are being done on the job. For example, while the student is learning about power tools for appliance repair on the job, he or she should be reading in the student's manual about power tools. This combination of classroom study and the actual work on the job gives the student well-rounded knowledge and experience about each specific operation.

Parts of an Assignment

Objectives. In order for the student to know what he or she should learn, each assignment begins with a list of objectives. The student should study the objectives before reading the information part of the assignment. After finishing the assignment, the student should reread the objectives to see if she or he has succeeded in meeting them. Success is checked through the use of the exercise and the assignment test.

Information. All the information for each assignment is given in the assignment itself. The exercise and the assignment test for each assignment are based on the information in that assignment. The student should read all the information carefully before answering the exercise questions. Any illustrations should also be studied. Tools and materials may be shown, as well as certain procedures and operations. The student should reread any information that is unclear when answering the exercise questions. Certain tasks on the job may also make it necessary to refer back to the assignment information.

Exercise. The exercise questions are based on the information given in the assignment and are designed to help the student meet the objectives. The student should write both the question and the answer on separate sheets of paper. The answer should be in the form of a complete sentence. After the instructor has checked the exercise questions, the student should correct any mistakes and place the papers in his or her notebook. If the exercise questions have been answered correctly, the objectives stated at the beginning of the assignment have been met. The exercise questions in this manual are designed to make the student think. The student should consider each question carefully before writing an answer.

Test. The assignment test is a short quiz of about five questions that may be answered very quickly. A test may be given as soon as the specific assignment has been completed, or several tests may be combined and given together as a weekly or six-weeks' test. The assignment test questions are either fill-in-the-blank or multiple-choice questions.

Exercise

1. What is a student's manual designed to present to the student?
2. What combination gives the student well-rounded knowledge and experience about each specific operation?
3. Name the four parts of an assignment.
4. When should the assignment objectives be studied?
5. What should the student do before trying to answer the exercise questions?
6. What may be shown in the illustrations?
7. When is it sometimes necessary to reread information in the assignment?
8. What is the purpose of the exercise questions?
9. In what form should the answers to exercise questions be written?
10. What should the student do with the exercise questions as soon as they have been checked by the instructor?
11. When may it be assumed that the assignment objectives have been met?
12. What are the exercise questions in this student's manual designed to do?
13. When may assignment tests be given?
14. What types of questions are found in the assignment tests?

A-2

Occupational Outlook for Appliance Repairers

Objectives: After completing this assignment, you will be able to—

1. discuss the advantages and disadvantages of appliance repair work;
2. tell where most appliance repairers work;
3. name the two fields of appliance repair; and
4. discuss the employment outlook for appliance repairers.

Nature of the Work

In the past, most household chores such as cooking and cleaning were performed by hand and often involved a great deal of time and physical effort. Today, a variety of laborsaving appliances make many household jobs much simpler to do. Microwave ovens cook meals in minutes. Washers and dryers clean clothes with little physical effort. Indeed, the number of household jobs machines can do is almost limitless. Even simple tasks such as cooking a hamburger or opening a can are done with appliances made specifically for those purposes. Servicing these machines is the job of the appliance repairer.

Appliance repairers usually specialize in servicing either portable appliances such as toasters and irons or major appliances such as refrigerators and ranges. In large repair shops, they may specialize in particular items such as clothes washers and dryers or refrigerators and freezers.

Portable appliances are worked on in shops. Major appliances usually are repaired in customers' homes by appliance repairers who carry their tools and a number of commonly used parts with them in a truck.

To determine why an appliance is not working properly, repairers operate it to detect unusual noises, overheating, or excess vibrations. They look for common sources of trouble, such as faulty electrical connections, and consult service manuals and troubleshooting guides. They may disassemble the appliance to examine its parts. To check electric systems, repairers follow wiring diagrams and use testing devices, such as ammeters, voltmeters, and ohmmeters.

After locating the trouble, the repairer makes the necessary repairs or replacements according to the type of appliance and defect involved. To fix a portable appliance such as a toaster, the repairer may replace a defective heating element. To fix a major appliance such as a washer, the repairer may replace worn bearings, transmission belts, or gears. To remove old parts and install new ones, repairers use common hand tools, including screwdrivers, soldering irons, files, and pliers, and special tools designed for particular appliances. Repairers operate the appliance after completing a repair to check their work.

Repairers may answer customers' questions and complaints about appliances and frequently advise customers about the care and use of the appliance. For example, they may show the owners how to load automatic washing machines or arrange dishes in dishwashers.

Appliance repairers may estimate and collect the cost of repairs. They also keep records of parts used and hours worked on each job.

Places of Employment

About 145,000 people were employed as appliance repairers in 1978, mostly in independent appliance stores and repair shops. Others worked for service centers operated by appliance manufacturers, department stores, wholesalers, and gas and electric utility companies.

Appliance repairers are employed in almost every community, but are concentrated in the more highly populated states and metropolitan areas.

Training, Other Qualifications, and Advancement

Most appliance repairers start as helpers and acquire their skills through on-the-job training. The type of training provided by employers varies among companies. In shops that fix portable appliances, new employees work on a single type of appliance, such as vacuum cleaners, until they master its repair. Trainees then move on to work on a different type of appliance. This process continues until they can repair a variety of appliances.

In companies that repair major appliances, beginners may be trained by experienced repairers during house calls. In other cases, they are taught while working in the shop rebuilding used parts such as washing machine transmissions.

Many helpers receive supplemental instruction through training seminars conducted periodically by appliance manufacturers. These seminars usually last 1 or 2 weeks and deal with the

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Information in this assignment comes from the *Occupational Outlook Handbook, 1980–81 Edition*, Bulletin 2075 (Washington, D.C.: Bureau of Labor Statistics, U.S. Department of Labor, 1980), pp. 332–333.

repair of one of the manufacturer's appliances. Up to 3 years of on-the-job training may be needed to become skilled in all aspects of repairing some of the more complex appliances.

Some large companies such as department store chains have formal training programs, which include home study courses and shop classes, where trainees work with demonstration appliances and other training equipment.

To become familiar with new appliances and the proper ways to repair them, experienced repairers attend training classes and study service manuals.

Formal training in appliance repair and related subjects is available from some vocational schools, technical schools, and community colleges. However, graduates of these schools must gain on-the-job experience to become fully qualified repairers.

Persons who want to become appliance repairers generally must have a high school diploma. Courses in electricity are essential because most repairs involve work with electrical equipment. Mechanical aptitude is also desirable. Appliance repairers who work in customers' homes must be able to get along with people.

Appliance repairers in large shops or service centers may be promoted to supervisor, assistant manager, or service manager. A few may advance to managerial positions such as regional service manager or parts manager for appliance manufacturers. Preference is given to those who show ability to get along with co-workers and customers. Experienced repairers who have sufficient funds may open their own appliance stores or repair shops.

Employment Outlook

Employment of appliance repairers is expected to grow about as fast as the average for all occupations through the 1980s. In addition to the jobs created by growth of this occupation, many openings will arise each year from the need to replace experienced repairers who retire, die, or transfer to other occupations.

The number of appliances in use is expected to increase very rapidly as the number of households grows and new and improved appliances are introduced. Maintaining this large number of appliances will increase the need for qualified repairers.

People who enter the occupation should have steady work because the appliance repair business is not very sensitive to changes in economic conditions.

Earnings and Working Conditions

Hourly earnings of appliance repairers ranged from $5 to $10 in 1978, based on the limited data available. The starting rate for inexperienced trainees was about $3.75 per hour. The wide variations in wages reflect differences in repairers' skill and experience, geographic location, and the type of equipment serviced.

Repair shops generally are quiet, well lighted, and adequately ventilated. Working conditions outside the shop vary. For example, repairers sometimes work in narrow spaces and uncomfortable positions amidst dirt and dust. Those who repair appliances in homes may spend several hours a day driving, although the use of two-way radios has decreased this time.

Although the work generally is safe, repairers could have an accident while handling electrical parts and lifting and moving large appliances. Inexperienced workers are shown how to use tools safely and how to avoid electric shock.

Appliance repairers usually work with little or no direct supervision. This feature of the job appeals to many people.

Some appliance repairers belong to the International Brotherhood of Electrical Workers.

Exercise

1. What are some advantages of appliance repair work?
2. What are some disadvantages of appliance repair work?
3. What organization do many appliance repairers belong to?
4. Where do most appliance repairers acquire their skills?
5. Where are major appliances usually repaired?
6. How does a repairer determine if an appliance is working properly?
7. Name the two fields of appliance repair.
8. Where do most appliance repairers work?
9. What is the employment outlook for appliance repairers?

Section

B

Safety

B-1. General Hand Tool Safety
B-2. Working Safely with Electrical Equipment
B-3. First Aid for Electrical Shock
B-4. First Aid for Accidental Injuries

B-1

General Hand Tool Safety

Objectives: After completing this assignment, you will be able to—

1. explain how edged or pointed tools should be handled;
2. tell what could result from using wooden-handled tools with loose or missing wedges in the handle;
3. tell why it is dangerous to use files for prying and to use driven tools with mushroomed heads;
4. give the safety precautions for using a grinding wheel and portable electric drill motor; and
5. name the safety precautions to take when installing temporary wiring.

Safety is a full-time job. For this reason, it is essential that all employees understand the nature of accidents and be familiar with hand tool safety, precautions, and safe practices.

Tools are expensive items and should be properly cared for at all times. Always use the proper tool for the job being done. Tools left lying on appliances after being used for repair work can cause serious damage to the appliance or the tool, or they may injure workers. Before you turn on any appliance, make sure that all tools have been removed.

Accidents can be prevented by paying attention to safety factors, organizing your job properly, and recognizing hazardous conditions. The use of sound common sense and care can prevent accidents to workers and loss or damage of materials or equipment.

Splintered wooden handles on hammers, hatchets, axes, picks, or shovels can be dangerous. Even a small splinter could cause a serious infection. Tetanus or gangrene could result from neglecting a splinter wound. Taping a cracked or splintered handle is a makeshift job and a dangerous practice. The handle should be replaced or the tool discarded.

Loose or missing wedges in a wooden tool handle could cause serious injury to another person if the tool should fly off the handle. For this reason, examine tools carefully before using them. Never use the back of an axe for hammering.

Pointed or edged tools that have become dull should not be used until they have been sharpened. You cannot do a proper job with worn-out or dull tools. A dull chisel could easily slip when hit and cause an injury.

When handing any edged or pointed tool to someone else, pass the handle first. This gives you control of the tool until the other person takes it, and an accident can be avoided should either one of you fail to judge the distance correctly. Edged or pointed tools should be handled and stored so that the points or edges cannot injure anyone.

Tools with tangs should always be used with a handle. A handle gives more control of the tool and prevents the tang from causing injury.

Chisels, screwdrivers, files, and rasps are made of hard, brittle metal. They should never be used for prying or hammering. Flying pieces of metal can cause bodily injury.

Screwdrivers are used every day by repairers. The blades should be kept square and flat. Worn or rounded blades could slip and damage materials or injure someone. Always select a screwdriver that fits the slot in the screw. Never use a screwdriver with a metal handle when doing electrical work.

Driven tools with mushroomed heads should be dressed before they are used. Star drills or masonry drills will develop mushroomed heads from the constant hammering when they are used. Flying particles of steel from such a head could cause serious injury to the hands, eyes, or other parts of the body. If a particle of steel should get into your eye see a doctor immediately because the steel will rust after about 4 hours. A handle with a rubber guard should be used on masonry drills.

When driving ground rods or using drills or chisels, a holding tool such as tongs or some other suitable device should be used when one person is holding and another is striking.

Wear goggles when using a grinding wheel if the machine does not have an eye guard. Do not let anyone stand directly in front of a grinding wheel because the wheel may break or shatter and cause serious injury or death. When handling small work, set the tool rest up close to the wheel so that the work cannot come between the tool rest and the wheel.

Use both hands when using a portable electric drill motor. Serious injury to your hands or injury from a fall could result if the drill bit should hang. Keep your hands clear of the bit and chuck when using a drill press. Always use the proper jig to hold the work, and never wear gloves when drilling small objects.

Use a closable electrician's knife for skinning wire, and work the knife away from you. Avoid the use of hooked cable knives or long pointed knives for electrical work.

Do not work in an awkward position when using a wrench. A skinned knuckle, a broken finger, or a serious fall could result. Work to one side when using heavy wrenches. Pushing on a pipe wrench with the work in front of your face is dangerous.

Carefully check all conduit hickeys or benders before using. A bent or broken hickey or bender can be dangerous. Sometimes when the coupling between the hickey and the handle is welded, the weld breaks. Sometimes the thread on the handle has been cut too short. This could cause the handle to break, resulting in a fall. If the thread on the handle has been cut too long, the handle will become loose. A bent or loose hickey handle could cause you to lose your balance. Avoid bending conduit on slippery surfaces. Select a proper bender or hickey for the job to be done. Use your leg and arm muscles to avoid injury to your back.

Do not use metal rulers or measuring tapes around energized circuits. A metal ruler or tape could fall or be dropped and come in contact with energized circuit or equipment. Using a metal ruler for electrical work is an unsafe practice.

Do not lean on protective equipment on energized circuits. Rubber blankets and other protective devices are usually a temporary safeguard. They could slip or be dislodged, leaving you no protection.

Repair or discard unsafe extension or temporary cords. Many fatal injuries have resulted from the use of unsafe extension cords. Be sure that the shells of all sockets on extension cords are connected to the neutral or grounded conductor. A polarized receptacle and cap should be used on extension cords.

Do not use an ungrounded or frayed extension cord when crawling under a building or while working on wet floors, steel structures, or damp areas.

Install temporary wiring safely to protect yourself and others. See that all joints are taped. Tape all bare and frayed places. See that the shells of all sockets are connected to the neutral or grounded conductor. Keep temporary wiring out of reach of persons standing on concrete floors or damp and wet areas when possible.

All portable electrical equipment should be properly grounded when in use. Grounding such equipment will prevent anyone from receiving an electrical shock in the event that a lack of proper insulation causes the frame of the equipment to become energized.

Exercise

1. How can using a tool with a splintered wooden handle be dangerous?
2. What could result from using a wooden-handled tool with missing or loose wedges in the tool handle?
3. Why is it dangerous to use tools with tangs without handles attached?
4. Why should you use both hands when using a portable electric drill motor?
5. How should temporary wiring be installed?
6. Why is it dangerous to use files for prying?
7. Why is it always advisable to pass edged or pointed tools handle first?
8. What two tools should not be used around energized circuits or equipment?
9. Why is it dangerous to use a driven tool that has a mushroomed head?
10. What precautions should be taken when using a grinding wheel?
11. Why should you never work in an awkward position when using a wrench?

Objectives: After completing this assignment, you will be able to—

1. name three safety precautions to observe while working on a live electrical circuit;
2. list three precautions for a safe inspection of a motor or generator while it is running;
3. give the precaution that should be taken to prevent someone from energizing a circuit being worked on;
4. name the tool and give the procedure for safely removing and installing fuses;
5. tell why the door on a safety switch should be closed when the switch is energized or de-energized;
6. tell when rubber gloves should be worn for working on live electrical circuits, and give a precaution that should be taken before the gloves are used;
7. tell why capacitors should be short-circuited before they are handled;
8. give the reason why the secondary terminals on a current transformer should be short-circuited before the secondary circuit is opened or broken; and
9. explain what should be done before operating such devices as motors or switch gear by remote control.

B-2

Working Safely with Electrical Equipment

Safe Handling of Electrical Equipment

Electrical equipment can be some of the most useful equipment in a shop or on the job. It can also be the most dangerous. It is very important that you acquire habits of caution. Careful, thoughtful, and deliberate work habits, if cultivated, will result in a safety-conscious attitude—the best way to prevent accidents.

The following rules of electrical equipment safety, as well as any other common sense safety rules, should be put into practice as soon as you enter the shop.

1. Never scuffle in the shop. Someone might be thrown into moving machinery, a "live" circuit, or other objects.

2. Never lean on any machine while it is in operation [illegible]

free, and you have no loose clothing.

5. Consider all electric wires "hot" until they have been tested.

6. Never place a soldering iron on any material that will burn.

7. Never operate arc welders, soldering transformers, or any machine that drills, grinds, or cuts without wearing the approved masks or goggles.

8. Never work on "live" circuits unless it is absolutely necessary. Make sure the circuit is dead and tagged, so that no one will turn the power on while you are working on it.

9. If you should find it necessary to work with a "live" circuit, have someone with you. Stand on a dry rubber mat or some other good insulator, and touch only one conductor at a time.

10. Keep your mind on what you [illegible]

Working on Energized Circuits and Equipment

Never lose your respect for the danger potential of electricity. However, do not be afraid of energized equipment or circuits. Fear could also be a hazard in doing electrical work. Even 110 volts can be fatal if you were "stuck fast" for any length of time. Even lower voltages can be dangerous, depending on how the current may travel through the body, whether you're wet or dry, or how well grounded you may be when you come into contact with the current.

A serious fall could result from the improper handling of lower voltages if you were on a ladder or scaffold. Exercise caution, and regard all electrical circuits as dangerous. When practical, shut off the power when working [illegible] warning tag and a lock on the switch to prevent someone from turning it on.

3. Do not attempt to install or remove a fuse from a switch unless it is fully open because a dangerous arc may result.

4. Use a fuse puller to safely install or remove fuses where no switch is provided. When removing a fuse, break contact with the energized or hot side of the circuit first. When installing a fuse, let the fuse make contact with the de-energized or cold side of the circuit first.

5. Before working on energized equipment, metal raceways, or boxes containing energized circuits, be sure they are grounded.

6. Be sure that the door is closed before energizing or de-energizing a safety switch gear unless you have enough room to protect yourself from an arc or flash. The arc or flash may burn your skin or damage your eyes.

7. Wear rubber gloves when working on circuits of 440 volts or more. Two qualified workers should be present when work is done on such circuits. Before working on energized circuits, be sure the rubber gloves have been electrically tested because a pinhole may result in electrocution. Do not use rubber gloves on circuits of 3,000 volts or over without additional protection. The gloves are not designed for working with such voltages.

8. Before handling or working on capacitors or condensers, short-circuit them with a jumper or iron bar. This will discharge the capacitor to prevent a dangerous shock.

9. Before breaking the secondary circuit on current transformers, short-circuit the secondary terminals to prevent the transformer from destroying itself.

10. Before operating any electrical equipment such as switches, switch gear, push buttons, or remote-control devices, be sure you understand the operation of the equipment.

11. Before operating remote-control devices such as motors or switch gear, be sure that no one is in a position where they can be injured when the equipment operates or that no one is working on the equipment.

12. Do not use aluminum or metal ladders to do electrical work.

Exercise

1. Why is it more dangerous to work around electrical equipment when you are wet or sweaty?
2. Rubber gloves should be worn when working on circuits of 440 volts or more. What precaution should be taken each time before the gloves are used?
3. What tool should be used to install or remove fuses when no switch is provided?
4. If it is necessary to work on a live circuit, what are three safety precautions to observe?
5. Why should capacitors be short-circuited before they are handled?
6. List three precautions to be observed when inspecting a motor or generator while it is running.
7. Why should rubber gloves not be used for working on circuits of 3,000 volts or more without additional protection?
8. Why should the secondary terminals on a current transformer be short-circuited before the secondary transformer is opened or broken?
9. Why should the door be closed on a safety switch or switch gear before it is energized or de-energized?
10. What precautions should be taken before operating remote-controlled devices such as motors and switch gear?

B-3

First Aid for Electrical Shock

Objectives: After completing this assignment, you will be able to—

1. name four common causes of accidental electrocution;
2. list five ways to remove a person from a live electrical circuit;
3. give two steps that should be taken immediately after a person has been removed from a live electrical circuit;
4. discuss the procedure for artificial respiration by the mouth-to-mouth method;
5. tell what should be done after the victim of electrical shock has been revived.

Electrocution is not a very pleasant word. It most often brings to mind thoughts of an electric chair. However, although many people have been electrocuted in prisons, accidental electrocution takes a far heavier toll of lives. Remember, accidents never happen. They are caused. Most accidental electrocutions are caused by carelessness, misuse of electrical equipment, faulty wiring or equipment, and improper installation

Slight shocks can be fatal. Every person should know how to remove a person from a live circuit and how to give artificial respiration. This is especially true of the electrical worker who may be able to save a fellow worker from fatal shock if he or she can begin treatment soon enough.

If you are ever with anyone who comes into contact with a live wire and cannot get loose, *turn the power off,* if you can, *without delay.* If the power cannot be turned off quickly, then remove the victim from the conductor without turning the power off. In this case, you must be very careful not to come in contact with the victim. Any good nonconductor can be quickly placed around the victim or the conductor to separate them. You may use a dry shirt or pair of pants, a rope, or a dry piece of wood. If the voltage is not too high, you can use the clothes on the victim. If you have any doubt as to whether the material will insulate you well enough, test it quickly while holding it in such a way that you can pull loose easily. It might be possible to cut the conductor between the victim and the power source with a pair of insulated side cutters or even a hatchet if the voltage is not too high.

After the victim has been removed from the circuit, check the mouth for foreign matter and to make sure the person has not swallowed her or his tongue. If breathing has stopped, give artificial respiration immediately. While giving artificial respiration, you must watch closely to make sure the person does not swallow his or her tongue.

One of the best methods of giving artificial respiration is the mouth-to-mouth (or mouth-to-nose) method. A good description of this and other methods, along with pictures of the various steps, may be obtained from the American Red Cross. In case you do not have one of the Red Cross pamphlets available, the following instructions should enable you to give artificial respiration successfully.

1. Lay the victim on his or her back. Tilt the head back so that the chin is pointing upward. Pull or push the jaw into a jutting-out position. These maneuvers should relieve obstruction of the airway by moving the base of the tongue away from the back of the throat.
2. Open your mouth wide, and place it tightly over the victim's mouth. At the same time, pinch the victim's nostrils shut, or close the nostrils with your cheek. (You may also close the victim's mouth, and place your mouth over the nose.)
3. Blow into the victim's nose or mouth.
4. Remove your mouth, turn your head to one side, and listen for the rush of air that indicates air exchange. Repeat the blowing effort at the rate of about 12 times a minute for an adult and about 20 times a minute for a child.

If you do not get proper air exchange, recheck the head and jaw positions. If you still do not get proper air exchange, quickly turn the victim on her/his side, and give several sharp blows between the shoulder blades. Again, sweep your fingers through the victim's mouth to remove foreign matter. If the victim is a small child, he or she can be suspended momentarily by the ankles or inverted over one arm and given two or three sharp pats between the shoulder blades to dislodge any obstruction.

If you do not wish to come in contact with the victim's mouth, commercial attachments may be used, or you may place a cloth over the victim's mouth or nose and blow through it.

Artificial respiration should be continued until all hope is gone. People have been revived after hours of artificial respiration. Therefore, it should be continued until a doctor or a responsible person who can be reached within a reasonable time has pronounced the person dead.

After the victim has been revived, he or she should be kept quiet, warm, and lying down until a doctor arrives. Keep a close check on the breathing to make sure it does not stop again.

Exercise

1. How long should artificial respiration be continued?
2. How can you check to see if proper air exchange is taking place?
3. What is the purpose of tilting the head of the victim back while giving mouth-to-mouth respiration?
4. What are two ways to give mouth-to-mouth respiration without making contact with the victim's mouth?
5. What precautions should be taken after the victim has been revived?
6. What are four common causes of accidental electrocution?
7. Name five ways to remove a person from a live circuit.
8. After the victim has been removed from the circuit, what two steps should be taken before giving artificial respiration?
9. What precautions should be taken before and during the time artificial respiration is being given?
10. If proper air exchange is not taking place, what should you do?

Objectives: After completing this assignment, you will be able to—

1. list five steps that should be observed to prevent infection of a wound;
2. give the only condition under which an injured victim should be moved;
3. name six conditions to look for in all injuries;
4. give the procedures for stopping bleeding when a vein is cut and when an artery is cut;
5. name four symptoms of shock;
6. describe first-, second-, and third-degree burns; and
7. tell how to give first aid for simple and compound fractures.

B-4

First Aid for Accidental Injuries

As long as accidents are going to occur, it is essential that a worker know the best thing to do under the circumstances. Under certain conditions, doing nothing might be the best thing for the victim of an accident. Much harm could be done to the victim if aid is not given properly. For this reason, the worker should learn to give aid that helps the one who needs it. Medical treatment should be obtained for all injuries.

Minor Injuries

The neglect of a slight injury can lead to a serious infection. Infection is the result of germs entering a wound or broken skin area. If injuries from splinters of wood or metal are not treated promptly and properly, they can become infected.

Apply an antiseptic and a sterile bandage to small cuts or wounds after the dirt or splinters have been removed. Puncture wounds from nails or splinters should be cleaned with an antiseptic, and a sterile dressing applied. Many wounds also require anti-

3. Do not apply salve to a wound or a burn because the salve may infect the wound.
4. Bandage all wounds loosely except where there is bleeding.
5. Change the dressings when they look soiled.

When going to the aid of an injured person, do not get excited. If the victim is conscious, try to keep him or her calm. Keep the crowd away, and see that a doctor or an ambulance is called. Do not give an unconscious person anything to drink. Do not move a seriously injured person unless it is absolutely necessary to prevent further injury from falling objects or debris. Never lift or move an injured person by the belt. Keep the victim lying down in a comfortable position with the head level until the extent of the injury is determined. In all injuries, look for the following conditions:

1. Serious bleeding
2. Stoppage of breathing
3. Shock
4. Burns

sure bandage will stop the bleeding.

If an *artery* is cut, bright red blood will spurt from the wound. Bleeding from an artery can usually be stopped by pressing a hand or finger on the proper pressure point or by using a tourniquet. A tourniquet should never be used except as a last resort—only if bleeding cannot be controlled by other means. Do not use a narrow material, such as a cord or wire, for a tourniquet. Do use a wide material, such as a belt, tie, or wide tape.

If the victim stops breathing, give artificial respiration, as was described for electrical shock.

Symptoms of Shock

Shock from an injury can be more serious than the injury itself. Seven symptoms of shock are listed here:

1. Skin is cold and clammy.
2. Eyes are wide and staring.
3. Pulse is weak and rapid.
4. Breathing is irregular.
5. Sweat may appear on forehead and palms of hands.
6. Severe chills [illegible]

the person flat on the back with the head slightly raised. Loosen the clothing, and keep the person covered if necessary. If blood is flowing from an open wound, use a pressure bandage to stop the blood. If blood comes from the mouth, eyes, ears, or nose, call a doctor quickly, and keep the victim quiet until the doctor arrives.

Eye Injuries

Get the victim of an eye injury to a doctor as soon as possible. Be sure to give the history of the eye injury, especially when chemicals are involved. The best first aid for chemical burns or injuries is flushing with water. However, an inexperienced person should never treat an eye injury.

Burns

Victims of severe burns should be kept quiet. Encourage the victim to drink water freely, and get him or her to a doctor as soon as possible. Sometimes a sterile pad soaked in a solution of baking soda and water is a simple first-aid dressing for burns. Do not apply cotton to a burn. The purpose of first-aid treatment of burns is to relieve pain and prevent infection. Burns are divided into three classes:

1. First degree—reddening of the skin
2. Second degree—blisters of the skin
3. Third degree—deep destruction of tissues

Fractures

Fractures are divided into two classes, simple and compound. A *simple* fracture causes no break in the skin. To care for a simple fracture, use splints and keep the fracture at rest. A *compound* fracture causes the skin and tissues to be punctured or torn. When a compound fracture is apparent, apply a sterile dressing, and then apply splints. Keep the fracture at rest, and control any bleeding that is present.

Exercise

1. What may result form the neglect of a slight injury?
2. What is the first-aid procedure for small cuts or wounds?
3. Under what condition should a tourniquet be used to stop bleeding?
4. Describe the three types of burns.
5. What first aid should be given for a simple fracture?
6. Name six conditions to look for in all injuries.
7. Shock from an injury can be more dangerous than the injury itself. Name the symptoms of shock.
8. Under what conditions should you move a seriously injured person?
9. What should be done when the victim of an eye injury is taken to the doctor?
10. What first aid should be given for a compound fracture?

Section

C

Hand Tools for Appliance Repair

C-1. Cutting and Driving Tools
C-2. Pliers, Wrenches, Clamps, and Vises

Objectives: After completing this assignment, you will be able to—

1. identify types of snips used in appliance repair;
2. discuss hacksaws;
3. discuss files and drill bits and their uses;
4. discuss hammers and their uses; and
5. discuss screwdrivers and how they are used.

C-1

Cutting and Driving Tools

Cutting Tools

Snips. Appliance repairers use snips on many jobs, such as installing vents or stacks. It is important to use the right snips for the specific job you are doing. This is safer, and it saves time and money.

Straight-pattern snips (fig. 1) are used for straight-line cuts and are available in lengths from about 7 inches to 13 inches. They can be used easily to cut out small notches where bends are to be made. They are also used to cut long straight lines.

Aviation snips (fig. 2) are usually 8 to 10 inches in length and come in three different styles. The straight-cutting style can be used to cut in either direction, although the right-hand and left-hand styles are made particularly for those types of cuts. Some people have trouble telling the difference between these last two styles, but they are easy to identify. When you are ready to cut the metal, if the upper blade is on your right, the snips are used to cut left-hand curves. If the upper blade is on your left, use them to cut right-hand curves. Aviation snips are the most popular of all hand snips.

Other snips that may be used are hawk bill, circular, bulldog (heavy metal), combination, bench, and compound lever. The compound lever is also used for heavy cuts.

Hacksaws. Hacksaws are used most often by appliance repairers to cut pipe into various lengths. The *depth* of a hacksaw is the distance from the cutting edge of the blade to the back of the frame. This is the actual depth the saw can cut. The *length* of a hacksaw is the approximate distance between the blade pins, not the overall length of the complete frame. Hand hacksaws are either nonadjustable, adjustable, or keyhole.

Nonadjustable hacksaws have a solid-back, nonadjustable frame. The frame is made for only one size of blade, usually a 12-inch blade. The main advantage of this saw is that deep or

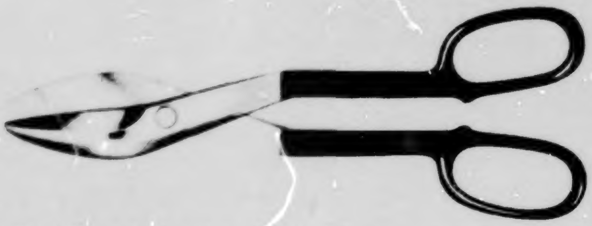

Fig. 1. Straight-pattern snips (Courtesy of Stanley Tools)

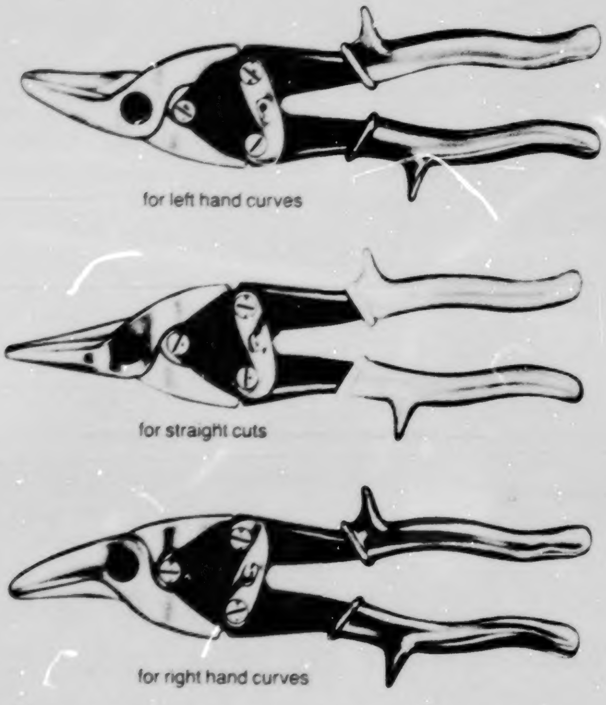

Fig. 2. Aviation snips (Courtesy of Stanley Tools)

long cuts into a sheet can be made without the back of the frame striking the work.

Adjustable hacksaws (fig. 3) are the most popular type and can take blades of 8, 10, or 12 inches. This saw consists of a rear square stretcher pin, a front-threaded stretcher pin with a wing nut, an adjustable telescoping frame in two parts, and a handle. The two stretcher pins may be changed so that the wing nut is at the rear if desired.

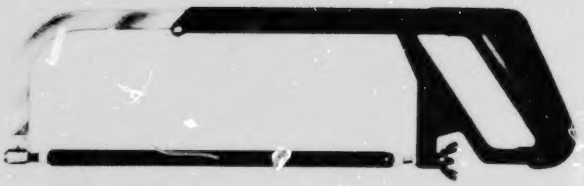
Fig. 3. Adjustable hacksaw (Courtesy of Stanley Tools)

The front leg of the adjustable frame has several notches cut along the bottom side. This leg may be slipped in or out of the rear leg by "bucking" the frame upward to release the notch from the pin in the rear leg. This positions the correct notch for the length of blade to be used. The frame is then snapped back straight. The two square stretcher pins must be aligned in one of the four positions in which they are to be used, with both pins facing in the same direction. The holes in the blade are inserted over the stretcher pins so that the blade is firm against the flat of the stretcher pin. The teeth are set to cut on the forward stroke. The wing nut is then turned tightly to stretch the blade to proper tension.

Keyhole hacksaws are used in tight places where saws with frames cannot be used. The keyhole hacksaw has only a blade and a handle.

The *pitch* is the number of teeth per inch on a hacksaw blade. Standard hacksaw blades come with pitches of 14, 18, 24, and 32 teeth to the inch. The appliance repairer mostly uses a pitch of 32 teeth to the inch for sheet metal sawing and 18 teeth to the inch for galvanized pipe sawing.

Always keep hacksaw teeth sharp and set. Do not twist the blade, as this may break it. Start all cuts with a forward stroke. Lift the saw slightly on the return stroke to keep from dulling the blade. Coat the hacksaw blade with oil when it is not in use.

Files. Files are important cutting tools. In use, the file is pushed across the surface of the work to remove excess material and to bring a part to its proper dimensions. The cutting action is done by teeth that have been raised from the surface of the file. These teeth bite into the material, removing small chips that are carried from the work in the openings between the teeth.

The various parts of a file are shown in figure 4. Regardless of length and shape, these terms apply to all standard files.

A file should never be used without a handle. Handles are usually wooden and are tapped on or are self-threading.

Although there are dozens of file types, the appliance repairer uses two main types. The *flat file* (fig. 5) in the bastard (double-cut) grade is used for thicker sheet stock or rods. The first third of the rectangular section from the heel is straight. The remaining two-thirds is bellied slightly toward the point or toe. Both edges are cut. All flat files are double-cut and may be found in bastard, second-cut, and smooth grades of teeth.

The *mill file* (fig. 6) is a single-cut file with a smooth shearing action that is excellent for sharpening other tools. It is also used to drawfile the edges of sheet metal. *Drawfiling* means pushing the mill file sideways over the metal surface. This leaves a smooth, almost polished edge on the metal. The forward stroke is the cutting stroke.

When filing, always be sure the work is held securely. Do not let the file slip off the work. Be careful not to let your hand slip and touch the sharp metal you are filing. During filing, downward pressure should be exerted from the elbows, with the wrists acting as equalizers. At first, heavy pressure is applied on the point of the file with

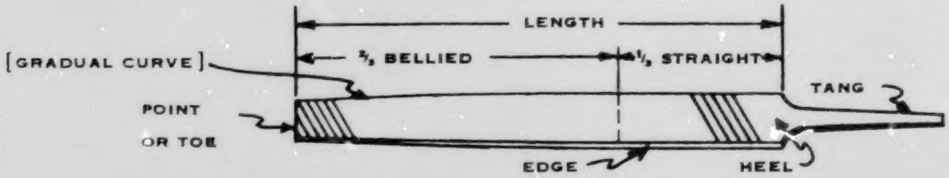

Fig. 4. Parts of a file

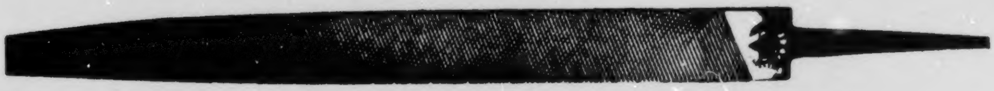
Fig. 5. Flat file

Fig. 6. Mill file

the left hand. This pressure is gradually reduced to nothing as the stroke progresses. The right hand at the same time increases pressure downward on the heel.

Filing skill is the ability to supply each tooth with equal downward and forward pressure as it cuts during the stroke. Lift the file slightly for the return of the file. Dragging a file backward over the metal will dull the teeth and heat the file.

A file is made from very brittle, hard steel. Anything that will dull sharp edges will dull file teeth. Never lay files across other files or tools or drop them on concrete floors. Store files in a rack if possible.

During use, files become clogged with chips. When this happens, tap the point against the heel of the hand or on a wooden bench to free the teeth of loose chips. Every so often the file should be "carded." Use a file card or brush that has wire bristles on one side and fiber bristles on the other to brush across the teeth parallel with the grooves.

Drill Bits. There are many types of drill bits, but the main type used in appliance repair is the *twist drill bit.* This bit has three parts—the body, the point, and the shank (fig. 7). The *body* may have two, three, or four flutes (spiral grooves), although two flutes are most common. The *flutes* form the two properly shaped cutting edges on the point and cause the chip to curl tightly within itself to occupy minimum space. The flutes also channel the chips out of the hole and allow lubricants to reach the cutting edges of the bit.

The *web* of a drill bit is the metal column that separates the flutes. It runs the entire length of the bit between the flutes and gives support. The cone-shaped end of the twist drill bit is called the *point.* The dead center should always be on the exact center of the axis of the drill. The *lips,* or cutting lips, are the cutting edges of the bit. In order to give a real cutting edge to the lips, their surfaces are ground away or relieved back of the lips. This relief, called *lip clearance,* is in most instances about 12°.

The sizes of twist drill bits are designated in one of four ways: (1) by numbers from 0 to 80, (2) by letters from A to Z, (3) by fractional inch sizes from 1/64 inch to 1 inch, and (4) by the metric system from 0.35 to 4.80 mm. The size is usually stamped on the end of the shank. But if the lettering is worn, you can find the size by using a vernier caliper, a micrometer, or a drill gauge. A drill gauge is a metal plate with holes of different sizes, corresponding to the different drill sizes.

The proper grinding or pointing of twist drill bits is best done on a drill grinding machine or with a drill grinding attachment on a bench grinder. You may grind the bits by hand if you have enough practice and sharpen them at the proper degrees. To repeat, the lip clearance should be about 12°. The dead center should be exactly centered on the axis of the drill at about a 59° angle to the face of the grinding wheel. A drill grinding gauge can be used to check the angle. Don't let the bit become too hot during grinding, or it will lose its temper. Grind in short stages to avoid this.

Driving Tools

Hammers. The primary hand tool for driving, pounding, flattening, and shaping objects is the hammer. There are several different shapes and types, each for a specific purpose. Hammers have two parts, the handle and the head. The handle, usually made of wood or of steel covered with a thick coating of plastic, fits into a hole, or eye, in the center of the head. The steel handle is forged to the head. The head of the conventional hammer has a cylindrical face and a peen or claw opposite the face.

The *ball-peen hammer* (fig. 8) has a head especially designed for driving and forming metals. The peen is rounded, or ball-shaped, and is used to flatten the ends of rivets or shape metals. The face is slightly rounded and is used to drive chisels, center punches, pin punches, and other metalworking tools. Ball-peen hammers come in sizes from 4 ounces up to 2½ pounds.

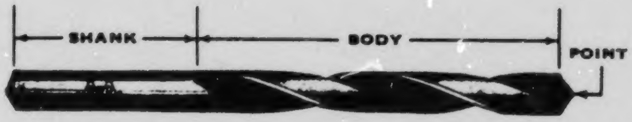

Fig. 7. Parts of a twist drill bit

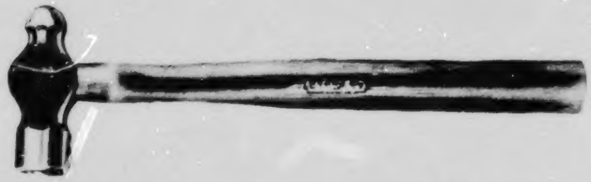

Fig. 8. Ball-peen hammer (Courtesy of Stanley Tools)

The *claw hammer* (fig. 9) is used mainly to drive and pull nails. Appliance repairers use it during installation operations. The claw end of the hammer is wedge-shaped to extract nails. The 16-ounce size is the most popular.

Soft hammers and mallets are used to pound or drive objects or do other jobs where a steel hammer would mar or break the work. These hammers are made from plastic, copper, lead, rawhide, wood, and rubber.

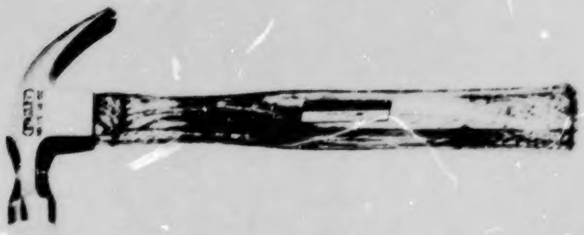

Fig. 9. Claw hammer (Courtesy of Stanley Tools)

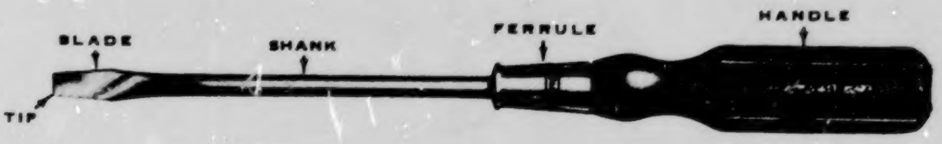

Fig. 10. Parts of a screwdriver (Courtesy of Stanley Tools)

Screwdrivers. The screwdriver is a tool designed to drive and remove screws. Sometimes workers use this tool as a chisel, punch, pry bar, or ice pick. This type of abuse soon ruins the screwdriver. Screwdrivers are classified according to the type of tip. The *standard* and *Phillips* screwdrivers are the most popular. Screwdrivers are sized according to the length from the blade tip to the handle—stubby, 2½, 3, 4, 5, 6, 8, 10, and 12 inches.

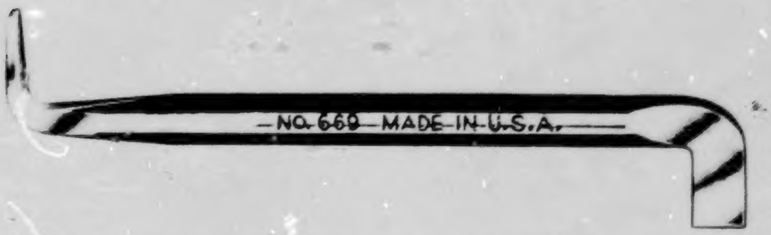
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Fig. 11. Offset screwdriver (Courtesy of Stanley Tools)

Although many different types and sizes of screwdrivers are designed to fit special jobs, most screwdrivers have the parts shown in figure 10. Basically, the parts are the handle, ferrule, shank, blade, and tip.

The *handle* of a screwdriver may be smooth, but it usually has grooves that help in gripping the handle firmly. The *ferrule* is the metal band or sleeve surrounding the lower portion of a wooden handle. It helps to anchor the shank in the handle and prevent the wood from splitting. Plastic-handled screwdrivers do not have ferrules.

The *shank* is the long steel portion extending from within the handle to the blade. It is usually round in small screwdrivers and square in larger, heavy-duty screwdrivers. The shank may be secured into the handle by using a rivet through the ferrule and shank, by forming and pressing the shank into the handle, or by molding the handle under high pressure (plastic handles).

The *blade* is the flattened, wedge-shaped end that is found on standard screwdrivers. The Phillips screwdriver does not have a blade. It has only the shank and the tip, although some manufacturers refer to the shank as the blade.

The *tip* of a screwdriver is that part of the blade that engages the screwhead. The two basic designs of tips for standard screwdrivers are the flange tip and the parallel tip. The flange tip is designed for general use.

The *heavy-duty screwdriver,* used by many appliance repairers, can be identified by its square shank. A wrench is applied to the square shank for added turning force. Pliers should not be used since they will roughen the shank or may slip, causing injury.

The appliance repairer may have jobs where there is not enough clearance for a standard screwdriver. The *offset screwdriver* (fig. 11) has one blade forged in line with the shank and the other blade at a right angle to the shank. Both blades are curved outward near the tips, creating the offset handle. The tool is available with a Phillips or a standard tip.

Exercise

1. Name the three styles of aviation snips.
2. How can you tell the difference between right-hand aviation snips and left-hand aviation snips?

3. How is the depth of a hacksaw measured?
4. What should always be used on a file?
5. What file is used for drawfiling edges of sheet metal?
6. What is used to clean loose chips from a file?
7. Which drill bit is used in appliance repair?
8. Name the four ways in which twist drill bits are sized.
9. What is a drill gauge?
10. How is the head of a conventional hammer shaped?
11. What is the peen of a ball-peen hammer used for?
12. When do appliance repairers use a claw hammer?
13. What are soft hammers and mallets used for?
14. How are screwdrivers classified?
15. What are the most popular types of screwdrivers?
16. How are screwdrivers sized?
17. How can a heavy-duty screwdriver be identified?

C-2

Pliers, Wrenches, Clamps, and Vises

Objectives: After completing this assignment, you will be able to—
1. describe various types of pliers and their uses;
2. discuss types of wrenches and how they are used; and
3. explain how clamps and vises are used in appliance repair.

Pliers

Pliers cause the most abuse of all hand tools. Improperly used, they may mar work, damage it beyond repair, and injure the worker. They are designed for no other purpose than holding and bending. Like all good tools, pliers should be kept clean and oiled on the joint pin to prevent undue wear and rust.

Pliers are sized by their overall length. The worker determines what size of pliers to use by the type of work to be done. The heavier the work, the larger the pliers should be.

Pliers are classified by the shapes of their noses and by the functions they perform. Although there are dozens of types of pliers, only those that appliance repairers would use are described in this assignment.

Combination slip-joint pliers (fig. 1) are by far the most common type. They are valuable utility tools if they are used corrctly. The slip joint permits the jaws to be opened to a wider position for gripping larger diameters. Such pliers are available in sizes of 5, 6, 8, and 10 inches. Most combination pliers have shearing jaws for cutting wire and copper pins. However, some are thin-nosed for use in confined places, and some have offset jaws.

Diagonal pliers are made with the cutting jaws at an angle of about 15° to the handles (fig. 2). The appliance repairer uses them to cut electrical wire. These pliers should never be used to hold objects or cut wire that is too large for their capacity.

Longnose pliers (fig. 3) are used mainly in electrical work where the long, slender jaws can reach into the work. They are sometimes used during soldering operations. These pliers should never be used for heavy-duty work.

Vise-Grip pliers (fig. 4) have powerful, adjustable jaws that may be locked tightly on the work. They may be used like a small vise to hold small work in place during drilling or soldering. They are also useful when a person is working alone or for holding nuts or bolt heads that have already been marred.

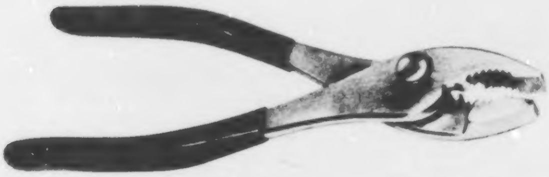

Fig. 1. Combination slip-joint pliers (Courtesy of Stanley Tools)

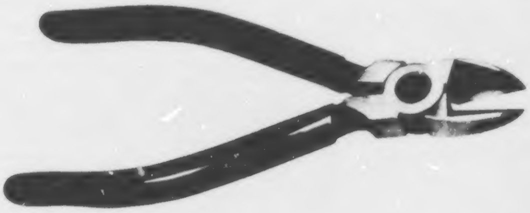

Fig. 2. Diagonal pliers (Courtesy of Stanley Tools)

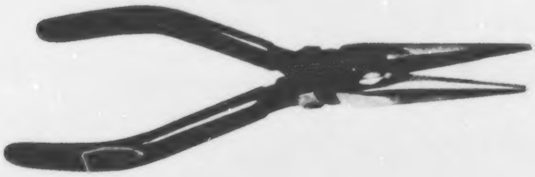

Fig. 3. Longnose pliers (Courtesy of Stanley Tools)

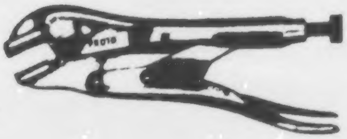

Fig. 4. Vise-Grip pliers

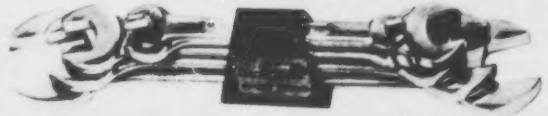

Fig. 5. Open end wrenches (Courtesy of Stanley Tools)

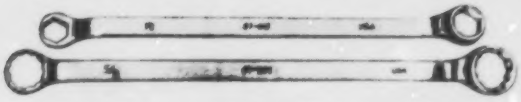

Fig. 6. Box wrenches (Courtesy of Stanley Tools)

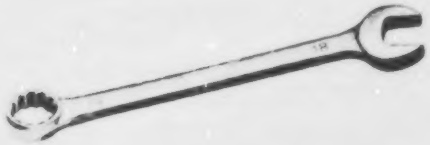

Fig. 7. Combination wrench (Courtesy of Stanley Tools)

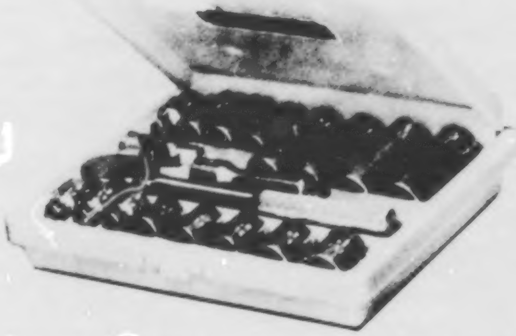

Fig. 8. Socket wrenches (Courtesy of Stanley Tools)

Wrenches

Many fasteners must be tightened with wrenches. Wrenches come in many types, sizes, and shapes. They are classified as either nonadjustable or adjustable.

Nonadjustable Wrenches. The *open end wrench* is the oldest of this type. The opening consists of two jaws that fit over the nut or bolt head (fig. 5). Usually, each end of the wrench has an opening, but some types have only one. The openings are of different sizes, usually one size apart. One open end wrench is actually two wrenches of different sizes. A set of ten or twelve of these wrenches gives a combination of sizes to fit most sizes of nuts. To designate an open end wrench, you should identify both opening sizes.

The jaws of open end wrenches are parallel and usually set at an angle of 150° to the handle. This enables the user to tighten the hex nut with a minimum of swing. If the wrench had straight jaws, it would have to be swung at least 60° to engage a new set of flats, since the angle between the flats is 60°. If the jaws are at an angle of 150° to the handle, the amount of swing required is halved. By turning the wrench over, the line of the jaws is changed 30° without changing the relative position of the handle. By turning the wrench over and completing another swing, a hex nut can be tightened.

The opening between the jaws is machined slightly oversize (usually 0.01 inch) to allow it to slide over the nut. The thickness of an open-end wrench usually varies with the strength of the metal from which it is made. Although the length of open end wrenches has not been standardized, most manufacturers make the length about twelve times the opening size. You will notice that small-sized wrenches are usually shorter than large-sized wrenches. The larger nut is harder to turn, so more leverage must be applied.

Box Wrenches. Box wrenches (or box end) completely surround or box in the nut (fig. 6). They usually have twelve points or notches inside, which allows the wrench to be swung in an arc as small as 30°. They engage the nut more securely than an open end wrench and are more useful in breaking a tight nut or tightening up a nut the last few turns. However, they must be lifted from the nut and then replaced at a new angle for each swing. This is a little slower than when using an open end wrench.

To correct this problem, some wrenches come with one open end and one box end (fig. 7). The box end is used for breaking or tightening a nut, and the open end is used for moving it up or down the threads. The two ends are the same size. These wrenches are called *combination wrenches* or *half-and-half wrenches*. Most box wrenches have handles that are not in line with the head, to allow room for the fingers on the underside of the wrench. These offset handles are angled from 15° to 45° from the box end.

Socket Wrenches. *Socket wrenches* are the fastest and easiest type of wrench to use (fig. 8). They have all the best features of both open end and box wrenches with the additional feature of being adaptable for use with a wide assortment of handles. The socket wrench, like the box wrench, has six, eight, or twelve points inside one end for engaging the nut. Opposite the box end is a square hole, or sometimes a hex hole, for receiving the drive of the handle.

There are several types of handles, but the appliance repairer generally

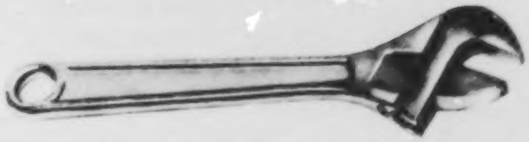

Fig. 9. Adjustable wrench (Courtesy of Stanley Tools)

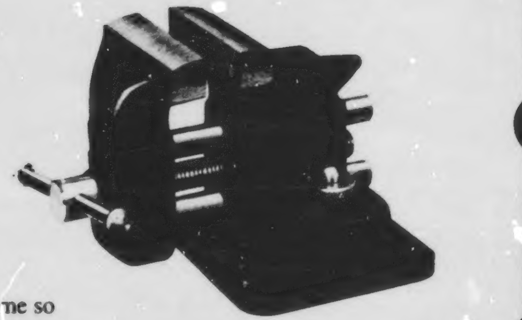

Fig. 10. Machinist's vise (Courtesy of Stanley Tools)

uses the ratchet or torque handle. The ratchet handle makes it possible for a nut to be tightened or loosened without removing the handle by means of a small shifting lug. The ratchet handle may be used in close quarters where the angle of swing is even less than 30°. The angle of swing depends on the number of teeth or points on the ratchet. The torque handle is used to measure visibly the amount of force being applied to the handle.

The size of the drive for a socket set usually indicates both the range and size of the sockets. A ¼-inch drive is usually the smallest and is used with lightweight sockets that range from ⅜ inch to ½ inch. A ⅜-inch drive works with heavier sockets that range from ¼ inch to ¾ inch. A ½-inch drive is used with the standard set of sockets ranging from ⅜ inch to 1⅛ inches.

Adjustable Wrenches. The adjustable wrench (fig. 9) has some of the desirable features of open-end wrenches plus provisions for adjusting the opening between the jaws. It is also known by the trade name *Crescent* wrench. Although useful in turning odd-sized nuts and bolts, it should not be used by the appliance repairer if an open end or box wrench of the proper size is available. The jaws engage the nut rather securely, but they require frequent readjustment to maintain the proper fit. These wrenches are sized according to the overall length, which ranges from 2 inches to 24 inches. Maximum jaw openings range from ⅛ inch to about 2½ inches.

Using a Wrench. The wrench must fit the nut or bolt head. Always use the correct wrench size. A wrench is made slightly oversize to enable it to fit easily, but not loosely, over the nut. Much more strain is put on the jaws of a loose-fitting wrench than on a properly fitted one.

Hex or square heads may become so battered through rough usage that the proper wrench will not fit. You may be tempted to use a larger size wrench that may slip once the battered edge of the nut gives way. This can cause skinned or bruised knuckles. If the flat of a nut is battered, it should be touched up with a file so that the proper size of wrench will fit.

If you have a choice, pull the wrench rather than push it. If a nut breaks loose suddenly while you are pushing with a lot of force, you may strike your hand against an object before you can stop it. If the wrench must be pushed, it may be done fairly safely in short, quick pushes. A wrench should never be hammered with a hard, heavy object.

Vises and Clamps

Vises are used primarily to hold pieces that are being worked on at the workbench or on machines. Clamps are used to hold together two or more pieces that are being joined, such as in welding, soldering, or brazing.

Vises. Vises should be mounted securely to a heavy bench or column so that they are steady when work is being clamped. Most appliance parts can be damaged if they are clamped directly between the hard, knurled steel jaws of a vise. "False" jaws should be placed over these surfaces. False jaws are made by cutting, bending, and fitting sheet lead, brass, copper, or aluminum around the rough jaws to give smooth surfaces.

The *machinist's vise* (fig. 10) is the most widely used holding tool in appliance repair work. It is used to hold pieces in a solid position so that both hands are free to file, drill, bend, assemble, or disassemble the work. Machinist's vises are sized according to the width of the jaws and the full opening between the jaws. For example, a *4½" × 6"* vise means a vise that has jaws 4½ inches wide with a 6-inch opening for work. Some vises have a swivel base so the vise can be rotated in different positions.

Clamps. Unlike vises, clamps may be carried about and used anywhere in any position. The most common clamps used by appliance repairers are C-clamps and spring clamps.

C-clamps (fig. 11) have a heavy iron or steel body made in the shape of a *C*, with a flat pad on one clamping surface and a screw pad on the other. Some handles are made of wing nuts, while others have bar handles or square heads to be tightened with a wrench.

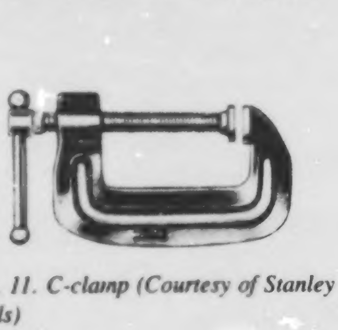

Fig. 11. C-clamp (Courtesy of Stanley Tools)

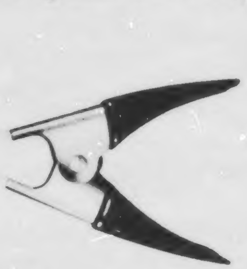

Fig. 12. Spring clamp (Courtesy of Stanley Tools)

C-clamps come in weights of light-duty, medium-duty, and heavy-duty. They are sized by the maximum distance between the clamping surface and the screw pad when they are fully open.

Spring clamps (fig. 12) are used to hold parts together temporarily while they are being soldered, brazed, or welded. They look like a large spring clothespin and only apply a small amount of pressure.

Exercise

1. What hand tool causes the most abuse of all hand tools?
2. What is the advantage of combination slip-joint pliers?
3. When does an appliance repairer use diagonal pliers?
4. How are wrenches classified?
5. On open end wrenches, what is the usual angle of the jaw to the handle?
6. How many points or notches are usually found inside a box wrench?
7. What are wrenches with one open end and one box end called?
8. What is the fastest and easiest type of wrench to use?
9. What does the angle of swing of a ratchet handle depend on?
10. What wrench should not be used if an open end or box wrench of the proper size is available?
11. What should be done if the flat of a nut is battered?
12. What is the most widely used holding tool in appliance repair work?
13. What clamp has a flat pad on one clamping surface and a screw pad on the other?
14. Name the clamp that looks like a large clothespin.

Section

D

Power Tools for Appliance Repair

D-1. Portable Drills
D-2. Drill Presses
D-3. Grinders

Objectives: After completing this assignment, you will be able to—

1. discuss the construction and types of portable electric drills;
2. describe the uses of portable electric drills; and
3. discuss the care and maintenance of drills.

D-1

Portable Drills

The portable electric drill is used by most appliance repairers. It may be used for drilling, polishing, grinding, and many other operations. It does these jobs with power, speed, economy, and convenience.

Drill Construction

Most workers use two basic types of drills, the small all-around quarter-inch drill and the larger half-inch drill. These drills get their names from the dimension of the largest drill shaft that can be inserted in the chuck.

Drill motors are the rugged universal AC-DC type. They are usually designed for intermittent operation. The no-load speed of the small ¼-inch drill is about 2,500 rpm. For the larger ½-inch drill, it is about 500 rpm. Drill motors are equipped with spur or helical gears in either single or double reduction. The combination of motor power, gear ratio, and gear reduction determines the amount of work power and torque delivered to the bit cutting edge.

To reduce maintenance and to provide uninterrupted service, the quality electric drill uses two types of antifriction bearings. Precision ball bearings are used at the spindle to absorb radial and end thrust. For high-load capacity at the motor, oilless bronze bearings are used.

The handle of the ¼-inch drill (fig. 1) is a pistol-grip type, formed to fit the palm comfortably and positioned for easy, convenient handling. The greater torque of the larger ½-inch drill requires two-handed control to keep the drill from twisting in the operator's hands. For this reason, manufacturers provide a spade handle on the rear housing and a switch handle. A removable pipe handle attaches to the side or top of the drill. These additional handles allow greater pressure when it is needed and provide control and versatility in larger drilling jobs.

Electric drills are equipped with either a two-wire cord or a three-wire cord and three-prong connector if they are indicated for industrial use. The third wire in a three-wire cord provides grounding protection when the three-prong connector is attached to a properly grounded supply system. Because some circuits do not have three-wire systems, adaptors are furnished with the three-prong plugs to convert them to standard two-hole receptacles. These adaptors have a pigtail that must be used to complete grounding protection.

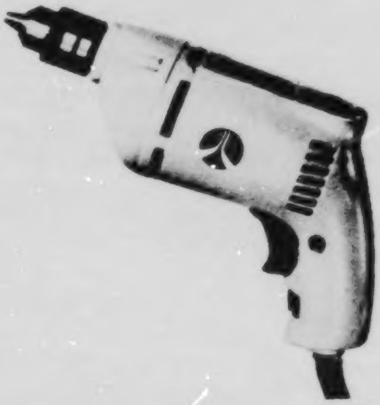

Fig. 1. Quarter-inch portable drill (Courtesy of Rockwell Manufacturing Co., Power Tool Division)

The three main types of chucks are the geared chuck, the hex key chuck, and the hand-tightening chuck (fig. 2). All of these, when properly used, perform safely and efficiently. Proper insertion and tightening of the bit or drill in the chuck is essential to safe, efficient operation, regardless of the type of chuck used.

The *geared chuck* requires the use of a special key to open and close each of the three jaws at the same time. The bit is released by loosening only one jaw with the key and turning the collar to free the others. The *hex key chuck* is opened and closed by a special hex key. Use the marks stamped into both the chuck body and the key socket as guides. To close the chuck, line up the marks, insert the bit, tighten it by hand, and then tighten it more with one turn of the key to the left or right. To release the jaws, align the marks once more, and loosen the sleeve by hand. The *hand-tightening chuck* is operated by holding one collar tightly while the other one is turned to open or close.

Wire Brush and Grinding Wheel

The wire brush and grinding wheel are generally used with a bench holder attachment or drill stand. They are used to remove tarnish or rust, sharpen hand tools, and remove peeling paint.

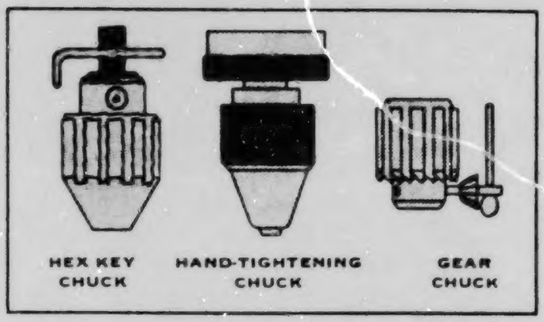

Fig. 2. Drill chucks

When using the wire brush, hold the work firmly, and keep it on the bottom half of the brush. After prolonged use, the wire strands wear in one direction and become dull. When this happens, turn the brush around on the spindle, and it will again cut quickly. To sharpen brushes, place a grinding wheel against the tips of the strands while the wheel is revolving.

Before mounting a grinding wheel, check it carefully for cracks. A cracked wheel can shatter during operation and possibly cause serious injury. Do not remove the paper blotters on the wheel since they absorb pressure from the tightening nut and prevent the wheel from cracking. Light, steady pressure gives the best results. Bring the material into the wheel gradually to prevent gouging or slowing down the motor. Then move the material slowly back and forth across the face of the wheel to prevent overheating and uneven wear on the wheel. When using either the wire brush or grinding wheel, always wear goggles.

Using the Drill

Although many people own or have used electric drills, not everyone uses them properly. Before drilling, select the proper drill or bit for the particular job to be done. If the drill bit is dull or warped, do not use it since it will make a hole larger than you want. Use a prick punch or awl to start the hole in order to center the drill bit. Otherwise, the drill bit will "walk" on the metal and move away from the proper location. This leaves undesirable marks on the surface of the metal.

Tighten the bit securely into the chuck of the drill. Hold the drill in a stationary position so that it cannot be moved while drilling. The drill should be fastened to a properly grounded outlet. If possible, place scrap material back of the hole to be drilled. Turn on the switch for a few seconds to see if the bit is running true. Place the point of the drill bit in the punched hole, hold the drill firmly at a 90° angle to the work, and apply even pressure. Do not force this feed pressure. After drilling, unplug the drill, and remove the drill bit from the drill.

Always keep in mind that this drill is electric and that precautions generally associated with electricity must be taken. Never use a damp drill or stand in water while using a drill. Never leave the drill plugged in unless it is in use. See that it is unplugged while making any adjustments.

When drilling, do not place your hand or fingers under or back of the stock being drilled. Do not remove the bit from the drill while it is hot unless you are wearing gloves or unless the drill bit can slip out without being touched.

Maintenance

A good electric drill is a precision tool and should be handled accordingly. After using the drill, blow all shavings and dust from the tool, and wipe off any oil or grease that has collected on it. The drill should be stored in a dry, safe place where it will not fall or have heavy objects thrown against it. The cord should be wound around it or placed out of the way. The cord should also be inspected periodically for cuts, cracks, or kinks. Check the manufacturer's instructions before attempting to lubricate the drill.

Exercise

1. What sizes of portable electric drills do most workers use?
2. Name the two types of antifriction bearings used in portable drills.
3. Why does the ½-inch drill usually require two-hand control?
4. Name the three main types of drill chucks.
5. What should be used with a portable drill when using a wire brush or grinding wheel?
6. Why should a dull or warped drill bit never be used?
7. What tool should be used to start a hole or center for the drill bit?
8. What should you remember about drill feed pressure?
9. What safety device should you wear while grinding with a drill?
10. Why should paper blotters be left on grinding wheels?
11. What should you do after you have finished using a drill?

D-2

Drill Presses

Objectives: After completing this assignment, you will be able to—

1. identify the parts of a drill press;
2. explain how to make drill press adjustments; and
3. discuss the use and maintenance of a drill press.

Parts of a Drill Press

The drill press is available as a bench model (fig. 1) or floor model. The size of the job to be drilled determines which model is necessary. The size of the drill press is twice the distance from the center of the chuck to the column. The basic parts of the drill press are the head, column, table, and base. You need to know the names of other parts, so they are described here. The numbers correspond to those in figure 1.

1. The cast-iron or steel *guard* protects the operator from the belt and pulley.
2. The *feed lever* or *handwheel* is made of cast steel or iron and is used to raise or lower the spindle when the machine is in operation.
3. The *motor,* which varies in size from ⅓ to ½ horsepower, provides the power for drilling. It usually revolves at about 1,750 rpm.
4. The *depth gauge* indicates the limits to which the spindle will travel downward.
5. The *chuck* consists of three jaws that tighten around the bit. It may be tightened with a chuck wrench or key.
6. The *column* is made of machined cast steel. It holds the table, head, and motor in the positions and heights needed.
7. The cast-iron *table* is fastened to the column and can be moved vertically, horizontally, or at different angles. Table sizes vary from 10 inches by 10 inches to 11 inches by 16 inches.
8. The *table clamp* locks the table to the column in any position desired.
9. The cast-iron *base* supports the machine.

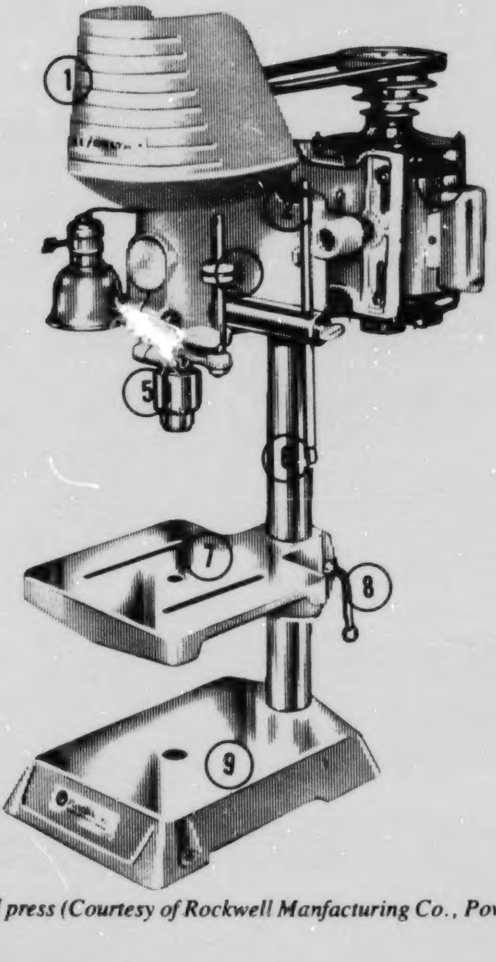

Fig. 1. Drill press (Courtesy of Rockwell Manfacturing Co., Power Tool Division)

Adjustments on the Drill Press

First select the drill size needed for the particular job at hand. Place the round shank drill between the three jaws of the chuck and tighten the chuck with the key. Always remove the key when you have finished tightening. One type of drill press has a tapered sleeve that receives drills with tapered shanks. The drills are held in place by friction and pressure. They may be removed by placing a tapered key in a sleeve slot and prying the drill out.

To drill holes at the correct angle, the table must be properly adjusted. Raise or lower it by loosening the table clamp at the column. Hold the table with one hand while you make this adjustment so that it will not drop down along the column. The table should be locked at a distance below the point of the drill equal to slightly more than the thickness of the material to be drilled plus the thickness of waste material to be inserted under it. The clearance hole in the table should always be directly below the center of the drill. The table should be level unless angle boring or other special work is to be done.

Setting the drill speed is important. The average drill press with a 1,750 rpm motor will give speeds of from 600 to 5,000 rpm at the spindle. The speed may be adjusted by changing the belt on the pulleys. Remember that large drills should be run at slower speeds than smaller ones. Remember, too, that when metal is being drilled, the drill speed is always slower.

Using the Drill Press

In most cases, drilling holes in metal requires the metal to be secured to the drill press table. Hand-screw clamps or C-clamps may be used. Unsecured metal may be caught by the drill bit and spun, causing serious injuries.

Before drilling, make a small indentation for the center of the hole. Let the drill turn at maximum rpm before lowering it to the indentation. Apply a constant pressure on the work, and see that the shavings are being carried out of the hole. When nearing the bottom of the hole, reduce the feed pressure to eliminate burring and grabbing of the bit into the metal. A fence (guide) may be used if you need to drill a number of parallel holes in the metal. If the drill bit begins to smoke, check it for sharpness, and check the speed and feed pressure.

Care and Maintenance

Drill presses should be placed near a wall, since the operator doesn't need to move around the machine. They should be located near a window for better lighting. Be sure the windows are closed when there is a great deal of moisture in the air to prevent rusting of the table and column. Do not set cold drinks on the table. Moisture forming on the bottom of the container will also rust the table. Keep a thin coating of oil or wax on all unpainted surfaces when the machine is not in use. Follow the manufacturer's recommendations on lubrication, and check belts now and then for wear. Be sure all bits are kept sharp.

Never turn on the machine when the belt guard has been removed. Make no adjustments while the electrical cord is plugged in. Fasten all material securely before drilling. Always keep your hands away from hot or spinning bits. Keep the area near the machine free of oil and scraps, since falls against sharp edges of the machine or against moving parts can cause serious injury.

Exercise

1. How is the speed of a drill press adjusted?
2. How is the size of a drill press determined?
3. What is the purpose of the feed lever or handwheel?
4. What part of the drill press indicates the limits to which the spindle will travel downward?
5. What should always be removed after a drill has been fastened in the drill press chuck?
6. What is the proper location of the clearance hole in the table of the drill press?
7. When should the drill press be run at slower speeds?
8. What may happen if the metal being drilled is not secured?
9. What should be done during drilling when you are nearing the bottom of the hole?
10. Why should moisture be kept away from the drill press?
11. What should be done while adjustments to the drill press are being made?

Objectives: After completing this assignment, you will be able to—

1. discuss types of grinders and abrasive wheels;
2. explain how to take care of and mount grinding wheels; and
3. give the various uses of grinders in the appliance repair shop.

D-3

Grinders

Types of Grinders

Some type of grinder is needed for all appliance repair shops since a variety of tools must be sharpened at various times. The most common type is the *horizontal spindle* type. It may be either a bench grinder or a pedestal grinder. The *bench grinder* (fig. 1) is more common because it takes up less space and can be mounted on a workbench. Some machines have special attachments for sharpening special tools. Most grinders are equipped with a tool holder that can be tilted at various angles. A small container may be found on the lower center part of the grinder. Water is kept in it to cool the tool as it is being sharpened.

Grinding Wheels

Grinding wheels are made of abrasives and a bond. Few people realize that certain materials should go into the grinding wheel for certain jobs. The bonds used are vitrified, silicate, shellac, and resinoid bond. *Vitrified bond* is adapted to the widest scope of grinding—both for fast stock removal and all classes of precision grinding. Its great advantage is that it is rigid and accurate. *Silicate bond* is used when the heat generated in grinding must be held to a minimum. *Shellac bond* is limited to operations where stock removal is slight. It is especially good for producing very high finishes. *Resinoid bond* is a synthetic resin and is used because it has a great amount of strength. It can be safely used at high speeds.

The abrasives used in grinding wheels are also important. Hard and tough *aluminum oxide* is ideal for heavy-duty work. It is also used for many precision applications where the shape of the cutting face of the wheel must be maintained. *Silicon carbide* is recommended for grinding low tensile strength materials, such as cast iron, aluminum, and brass.

It is important to select a wheel soft enough to wear away in use, and thereby keep itself sharp. The most common mistake is using too hard a wheel. This causes the abrasive grains to remain in the face of the wheel after it has become dull. This also leads to reduced output and burning or checking of the work surface.

Grinding wheels are usually reordered on the basis of the original equipment. However, you may choose to buy wheels of different grit and bond. You can use wheels of smaller dimensions provided they fit the spindle of the machine and are not run in excess of the rpm clearly marked on the wheels.

Mounting a Grinding Wheel

Always check the new grinding wheel to be sure that it does not have chipped edges or cracks on either face. To check for cracks, place a metal rod through the center of the wheel, and tap the side with a piece of wood. A clear ring indicates the wheel is sound and dependable. If there is a flat sound, look for small cracks that will make the wheel unusable. Unplug the machine.

Remove the nut and outside washer from the spindle, and remove the old grinding wheel. Clean all grease and metal dust from the spindle and wash-

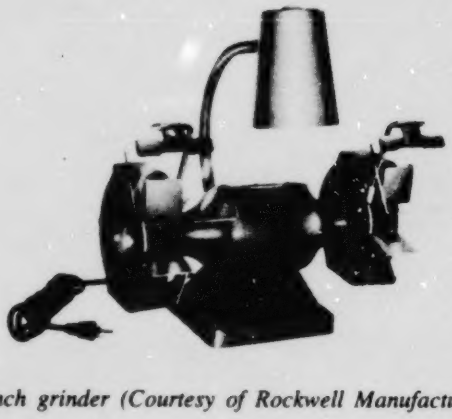

Fig. 1. Bench grinder (Courtesy of Rockwell Manufacturing Co., Power Tool Division)

ers. Cut out two paper washers from a soft, thick paper, such as blotting paper. Place one paper washer against the inside metal washer. Install the new grinding wheel. Then place the second paper washer and outside metal washer on the spindle. These metal washers are sometimes called flanges. Tighten the assembly with the nut. Do not exert too much pressure, as this can fracture the new grinding wheel.

Flip the grinder switch on, and then immediately turn it off. This gives enough speed to see if the wheel is in balance. If it is out of balance, it must be *dressed* (trued). Never stand in front of the wheel while you are testing it for balance.

Dressing a Grinding Wheel

The grinding wheel dressers commonly used are the abrasive stick, the mechanical dresser, and the diamond dresser. The *mechanical dresser* has a cutter that turns against the wheel. It breaks out some of the wheel grains and gives new cutting edges to the abrasives. This dresser is inexpensive and is usually sufficient for an appliance repair shop. The *abrasive stick* is also inexpensive. It is either round or square and fits in a metal holder so it can be pushed into the grinding wheel. The *diamond dresser* is much more expensive. However, because of its extreme hardness, it can dress the grinding wheel to do fine precision grinding.

During the dressing (or truing) operation, always take small or light cuts. Hold the dresser steady as you move it across the edge of the wheel. Jerky movements will cause grooves that are hard to take out. The speed at which you move the dresser determines whether the grinding wheel will give a high or low finish to the object to be ground. Be careful not to move it too slowly, or the wheel may become glazed. The diamond dresser is usually held at a slight angle (about 12°) to the wheel during the dressing process.

Using the Grinder

Most of the grinding jobs in the shop involve sharpening tools. Several things should be kept in mind when using the grinder. Never force work into the grinding wheel. This will cause undue wear on the abrasive materials. It may also slow the grinder, burn the tool, and break or groove the wheel. Always see that the wheel is turning at maximum rpm during use. Tools being sharpened should be held securely against the tool rest. The tool rest must also be securely fastened during grinding operations. Always take light grinding cuts, and remove the object often enough to prevent burning.

Care and Safety

All grinding wheels are breakable, and some are more fragile. Great care should be exercised in handling and storage to prevent damage that might cause a wheel to fly apart when brought up to maximum speed. Handle wheels carefully to prevent dropping or bumping. Do not expose wheels to dampness or extreme temperatures. These conditions could cause the bonding material to break away from the abrasive materials.

Mounting washers or flanges must be at least one-third the wheel diameter. They should not bear against the reducing bushing. This gives support to the sides of the grinding wheel and helps prevent breakage.

Always wear goggles or safety glasses when dressing the wheels or when using the grinder.

Exercise

1. What is the most common type of grinder?
2. What are the two ingredients that make up a grinding wheel?
3. Which bond is adapted to the widest scope of grinding?
4. Which bond is used in wheels where the heat generated in grinding must be held to a minimum?
5. How do you check a grinding wheel for cracks?
6. What could fracture a new grinding wheel?
7. What are the metal washers on each side of the grinding wheel called?
8. What must be done if the wheel is out of balance?
9. Name the three common types of grinding wheel dressers.
10. What kind of cuts should you make when dressing a grinding wheel?
11. What jobs are usually done with the grinder in the sheet metal shop?
12. What does forcing work into a grinding wheel cause?
13. What conditions should wheels not be exposed to?
14. What size should mounting flanges or washers be?
15. What should you wear during dressing and grinding operations?

Section

E

Introduction to Electrical and Magnetic Fundamentals

E-1. Magnetism
E-2. Electricity
E-3. Electromagnetism
E-4. Units of Electrical Measurement

Objectives: After completing this assignment, you will be able to—

1. describe a *natural* magnet and an *artificial* magnet;
2. give examples of magnetic and nonmagnetic substances;
3. tell what happens between like poles of two magnets;
4. tell what happens between unlike poles of two magnets;
5. explain what happens to the magnetic field intensity between unlike poles of two magnets as they are moved away from one another; and
6. define the terms *retentivity* and *residual magnetism.*

E-1

Magnetism

Electric force and magnetic force are the two invisible forces that are primarily responsible for the industrial and scientific wonders of today. Early students of science believed that magnetism was an independent phase of science that was similar to electricity but quite different. Today it is generally recognized that the study of magnetism is a branch of electricity. These two forces make possible the operation of electric motors, generators, lights, doorbells, measuring instruments, and other electrical apparatus. They also compose the invisible electromagnetic waves that travel through space to make radio, radar, television, and other electronic communication systems possible.

Early History of Magnetism

The ancient Greeks knew that certain stones found in the town of Magnesia in Asia Minor had the property of attracting bits of iron. Quite appropriately, they called these stones *magnetite.* Legend tells of a shepherd who thrust his iron staff into a hole containing magnetite and found to his dismay that he was unable to remove it. Another story dating back 2,300 years relates how Ptolemy Philadelphos had the entire dome of a temple at Alexandria made of magnetite in order that he might suspend a statue in midair. The experiment was a failure. Today it is known that magnetite is an iron ore with magnetic qualities. In other words, magnetite is an unrefined product of nature and is a *natural magnet.*

The Orientals discovered that if a piece of magnetite was mounted or suspended in a horizontal plane and allowed to rotate it would turn so that a particular end always pointed north. Europeans learned of this discovery and used it to make the magnetic compass to aid in navigation. Because of this property, the piece of magnetite came to be known as a *leading stone,* or *lodestone,* and the end that pointed toward the north was called its north pole. The opposite end of the lodestone was called its south pole. Therefore, each lodestone, or bar magnet, has a pair of poles. It was found also that the invisible magnetic force caused the north pole of one lodestone (magnet) to be attracted to the south pole of another lodestone and that like poles (south to south or north to north) of two magnets repelled one another. In other words, the magnetic force between two like poles is one of mutual repulsion, and the force between two unlike poles is one of mutual attraction.

Artificial Magnets

Although pieces of magnetite are natural magnets when taken from the earth, they now have only historical value. Better magnets can be made from pieces of iron or steele by artificial means. Artificial magnets are made in a wide variety of sizes and shapes and are used extensively in electrical apparatus. The bar magnet, horseshoe magnet, toroidal (doughnut-shaped) magnet, and compass needle are common types of artificial magnets.

A representation of the magnetic field about a bar magnet can be obtained by means of the following experiment with iron filings.

1. This experiment can be performed by placing a piece of paper over a tabletop and sprinkling some iron filings over a large area of the paper (fig. 1A).
2. A bar magnet is then dropped into the center of the area containing the filings (fig. 1B). As the magnet reaches the table, many of the filings near the poles of the magnet are attracted to the magnet, and most of the other filings move slightly. In short, the filings rearrange themselves because of the magnetic field about the magnet.
3. If the table is gently tapped, the filings completely rearrange themselves in a pattern similar to that shown in figure 1C. Regardless of the number of times that the experiment is repeated, the filings will always arrange themselves in about this same pattern.
4. Pieces of iron or steel become magnetized by induction when they are brought in contact with, or close to, a magnet. Thus, each of the tiny iron filings about the bar magnet becomes a small magnet with a north and south pole of its own. Each of these filings (or magnets) is affected by the

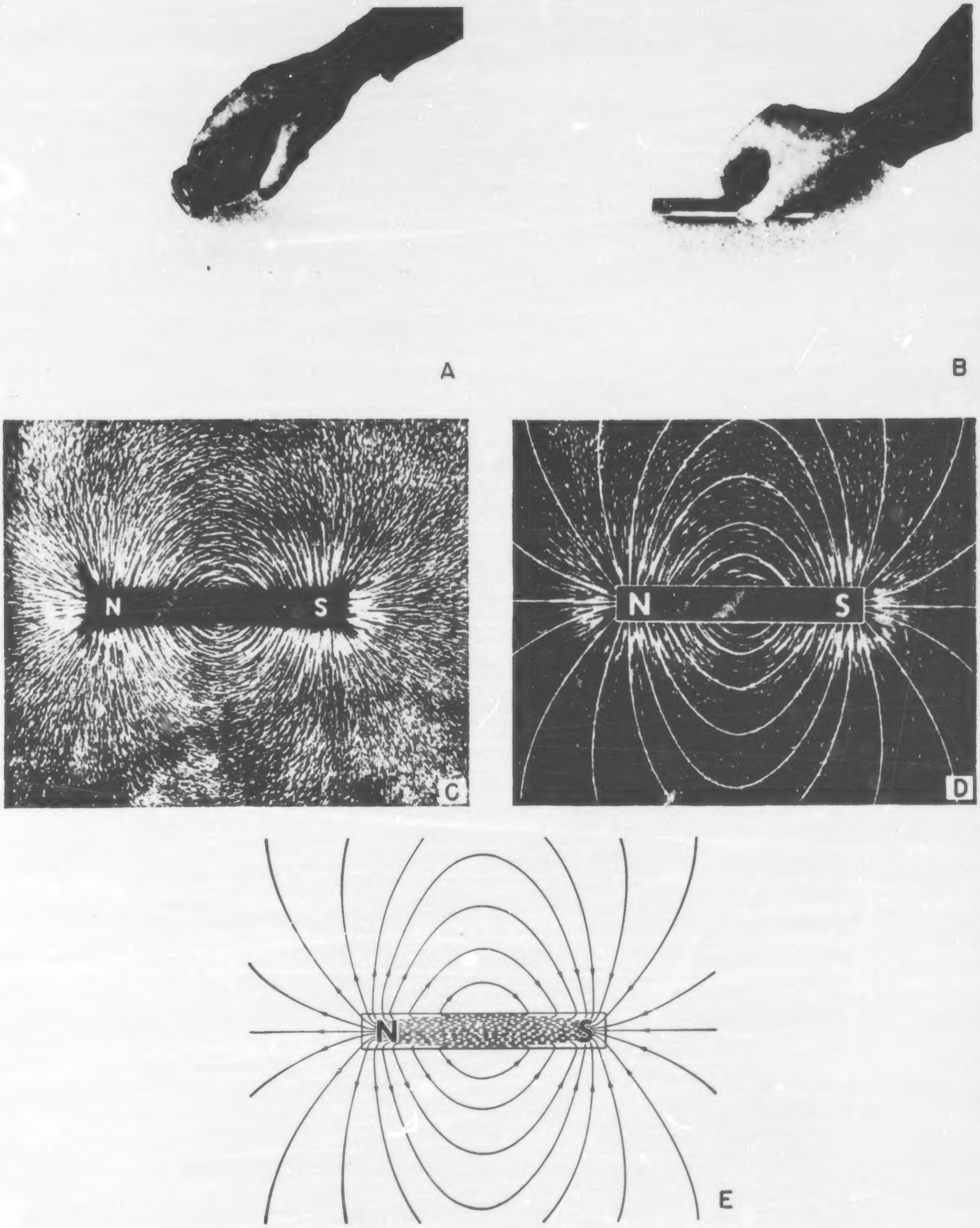
A
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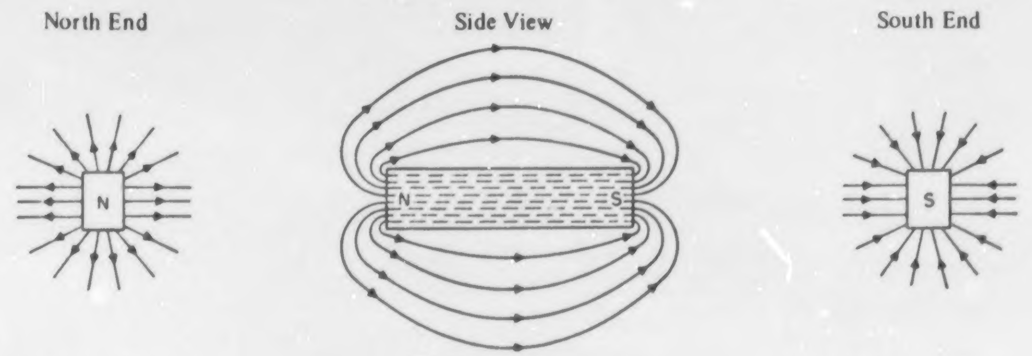
Fig. 1. The pattern formed by iron filings about a bar magnet represents the magnetic field about the magnet.



Field of force about north pole. Lines leave pole in all directions.

Field of force about a bar magnet. Lines of force shown in one plane only. Actually, lines extend in all directions as shown in end views and, theoretically, throughout all space.

Field of force about south pole. Lines enter pole from all directions.

Fig. 2. The field of force extends in all directions about a bar magnet.

direction and intensity of the magnetic field about the bar magnet and aligns itself in the same manner as a compass needle, in response to the magnetic field.

5. The force of the magnetic field is greatest near the poles. Many of the filings are attracted and adhere to the magnet showing distinct alignment. As the distance from the poles increases, the field becomes less intense, and the action of the force on the iron filings is less apparent. At the edge of the pattern (see fig. 1C), the effect on the filings is hardly noticeable.

This iron filings experiment has long been used to represent the nature of the magnetic field about a magnet. It gives an idea of the direction and intensity of the magnetic forces that act in the field. However, the pattern formed in this experiment *is not the magnetic field itself,* but only a representation of the way in which the magnetic forces in the field act on magnetic substances within the field. The magnetic field is invisible.

Suppose you want to draw a representation of the direction and intensity of the magnetic field about a magnet. This can be done by drawing a picture of the pattern obtained when iron filings are placed about the magnet. In the case of a bar magnet, such a drawing would be similar to that shown in figure 1D. However, this method is difficult and time-consuming. A simpler and more commonly used method is that of arbitrarily representing the forces in a magnetic field by drawing a few lines called *lines of force*.

Figure 1E shows lines of force as they are usually drawn to represent the magnetic field about a bar magnet. The overall pattern of these lines of force is similar to that formed by the iron filings about the magnet. Note that arrowheads have been placed on each of the lines of force shown in figure 1E. Also note that the direction of each arrowhead is away from the north pole and toward the south pole of the magnet. In other words, the arrowheads indicate that lines of force leave the magnet at the north pole and enter the magnet at the south pole. Within the magnet, the direction of the force is assumed to be from the south pole to the north pole, so that a continuous loop is formed by each line of force. The direction of these lines was defined arbitrarily long ago as the direction in which the north pole of a compass needle will point if placed at any point along a line of force.

Actually, the magnetic field completely fills the space about a magnet and does not exist only in a single plane, such as along a tabletop. This field can also be shown to extend out to great distances and, theoretically at least, throughout all space, with the intensity of the field decreasing very rapidly as the distance is increased. Figure 2 shows how the field of force extends in all directions about a bar magnet. The end views show the lines of force leaving the north pole and entering the south pole.

Lines of force are also used as an indication of the strength or intensity of the magnetic field. Figure 3 shows that magnetic force (field intensity) varies inversely with the square of the distance. This law is not strictly true in practice since it is based on the assumption that the lines of force from a pole face emanate from a point somewhere within the magnet. Actually, the lines of force do not converge to a single point within the magnet.

Figure 3 shows a magnet face with an area of 1 square centimeter. You can see that more lines of force pass through the square centimeter area ABCD than the area EFGH, which is the same size but is located some distance from the pole face. This means that the field intensity is greater in area ABCD than in EFGH, as shown by the greater number of lines passing through ABCD. The farther

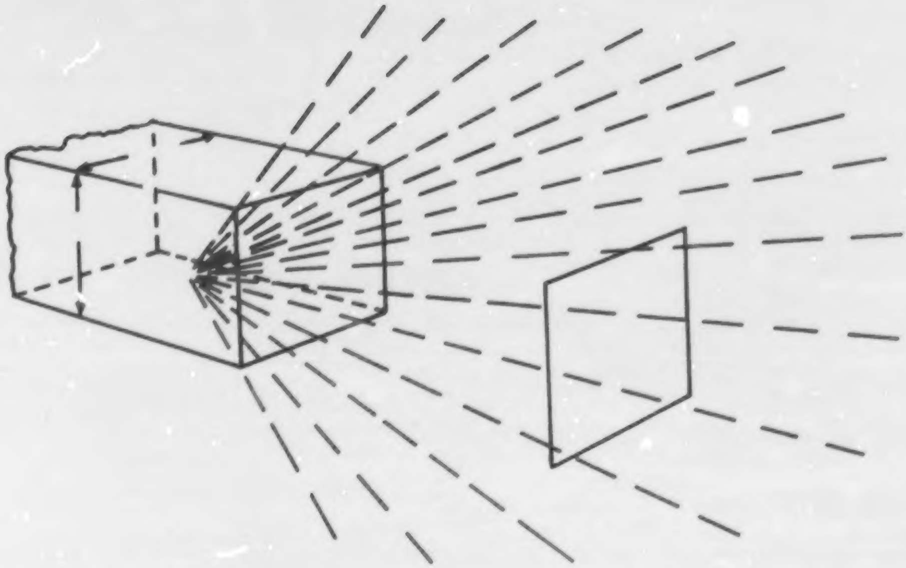


Fig. 3. The field intensity varies with the distance from the pole.

away from the pole, the less the field intensity will be. When the lines emanate from a point, the number of lines through a given area will vary inversely with the square of the distance that the area is from the point—not from the pole face. With a long magnet, the field intensity will be nearly as shown in figure 3, and the law, the inverse as the square of the distance, will be almost true. If the magnet is short and thick, however, the field will be more uniform for quite a distance from the pole and the distance-square law will be less precise.

Characteristics of Magnetic Fields

Thus far only the pattern of the magnetic field associated with a single bar magnet has been considered. Actually, this pattern of the magnetic field is only one of an unlimited number of possible patterns that can be produced by using one or more magnets.

If the area surrounding the north pole of one bar magnet and the south pole of a second bar magnet is sprinkled with iron filings, the pattern shown in figure 4A will appear. Note the similarity between this pattern and the pattern of filings about a single bar magnet. Figure 4B shows the distortion of this magnetic field that occurs when a third magnetic pole is brought into the region. Note that the intensity of the magnetic field is greatest near the poles of the magnets. In figure 4B, note the small area midway between the two like poles where the filings appear to lie as though unmagnetized. This is actually the case because midway between the two like poles the magnetic force produced by one pole is equal to, and in opposition with, the magnetic force produced by the other pole.

Figure 4C further illustrates the manner in which magnetic forces act to produce a magnetic field. In this case, the magnetic field contains forces of repulsion. Again, note that the magnetic force is strongest near the poles and decreases very rapidly as the distance from the poles is increased, while at a point midway between these like poles there is a magnetic field of zero intensity.

Temporary Magnets

It has been found that pieces of iron and steel become magnetized when they are brought in contact with, or close to, a strong magnet. This process is called *inducing magnetism*. For example, the iron filings in the previous experiment each became a tiny magnet by induction. The filings, however, were made of soft iron. Therefore, they retain their magnetism only as long as they remain in the space about the bar magnet. When the filings and bar magnet are separated, the filings lose their magnetism very rapidly. For this reason, magnets made from soft iron are called *temporary magnets*.

Permanent Magnets

If the filings used in this experiment had been made from steel instead of soft iron, the same results would have been obtained, except that the steel filings would have retained their magnetism for a longer period of time after having been separated from the bar magnet. Thus, hundreds of tiny permanent magnets would have been made because any magnet that retains its magnetism over a long period of time is called a *permanent magnet*. The amount of magnetism retained by a material after the magnetizing force has been removed is called *residual magnetism*.

Magnetic and Nonmagnetic Substances

It has been shown that the invisible magnetic force that exists in the space surrounding a magnet is capable of attracting pieces of iron and steel. For this reason, iron and steel are called *magnetic substances*. Other magnetic substances are attracted by a magnet though not as strongly as iron and steel. The more common ones are cobalt, nickel, and manganese. However, some of the best permanent magnets are made from alloys of these substances.

The ability of a material to retain its magnetism is called *retentivity*. Since steel retains its magnetism longer than soft iron, steel has greater retentivity than soft iron. Therefore, a material with good retentivity will have a large amount of good residual magnetism and will make a good permanent magnet.

Other substances that are not attracted by a magnet are said to be nonmagnetic. Examples of these *nonmagnetic substances* are air, wood, paper, glass, copper, aluminum, lead, tin, and silver.

Magnetic force *acts through any nonmagnetic substance*. This may be demonstrated by moving a permanent magnet beneath a piece of paper or glass on which is sprinkled iron filings. As the magnet moves, movement of the filings can be observed. There is no known insulator against magnetic lines of force. Magnetic force is mutual to both a magnet and a magnetic substance. For example, a magnet is attracted to a firmly held piece of iron or steel just as strongly as the iron or steel is attracted to the magnet.

The Earth as a Magnet

The fact that a suspended magnet anywhere upon the surface of the earth always points toward the north indicates that the earth itself is a huge natural magnet (see fig. 5). Note that the poles of the magnet are far below the surface of the earth and that the magnet is somewhat inclined from the north and south geographic poles. Since the pole of any compass points to the north, that magnetic pole of the earth that is near the north geographic pole must be of south magnetic polarity, as shown in figure 5. The north geographic pole is referred to as *true north* and the south geographic pole as *true south*. The deviation from the true north, which at some places is very large, is called the *magnetic declination* of the station. Remember that *magnetic north* is merely the direction in which the north end of a compass needle points.

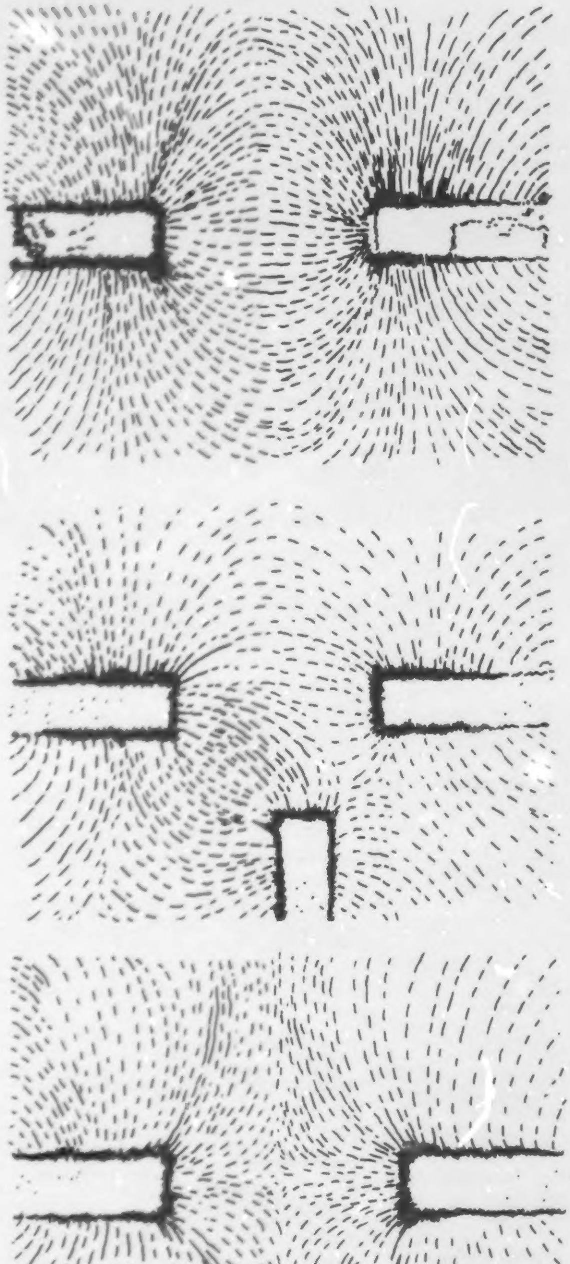


Fig. 4. Magnet field patterns

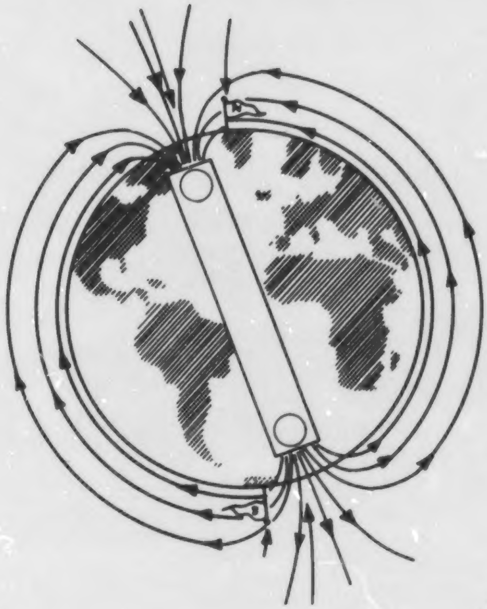


Fig. 5. The earth acts as a magnet.

Exercise

1. What is a *natural* magnet?
2. What is an *artificial* magnet?
3. From which pole of a bar magnet do the magnetic lines of force leave?
4. What is a magnetic substance?
5. Give examples of magnetic substances and nonmagnetic substances.
6. What is *retentivity?*
7. How do like poles of two magnets affect one another?
8. How do unlike poles of two magnets affect one another?
9. Why is soft iron considered a temporary magnetic substance?
10. How many pairs of poles does a magnet have?
11. What is *residual magnetism?*
12. What type of material is a good insulator against magnetic lines of force?
13. If two magnets with unlike poles are slowly moved away from one another, how does this affect the intensity of the magnetic field between the magnets?

Objectives: After completing this assignment, you will be able to—

1. name the two kinds of electricity;
2. tell how positive and negative charges affect each other;
3. explain how electrical force differs from magnetic force;
4. discuss the structure of matter;
5. tell why certain elements are the best conductors;
6. explain how current electricity is produced; and
7. define *electromotive force.*

E-2

Electricity

Early History of Electricity

The ancient Greeks learned that a magnetized piece of iron is not the only substance about which exists an invisible force capable of attracting objects. They found that a yellowish resin called amber, if rubbed, would attract small bits of wood shavings. They also learned that the invisible force about a piece of amber so rubbed is *different* from the force about a magnetized piece of iron. That is, the force about the amber, a nonmagnetic substance, does not attract magnetic substances, while a magnetic force does not attract nonmagnetic substances such as wood shavings. Later it was discovered that many other substances such as glass and rubber, after being rubbed with a piece of fur, wool, silk, and so forth, exhibit the same characteristics as amber. That is, they attract bits of paper, wood, and certain other light objects.

In an attempt to explain the nature of this force, William Gilbert (1600) divided all substances into two classes—electrics and nonelectrics. He classified an electric as being any substance possessing the property of amber and a nonelectric as being any substance *not* possessing the property of amber. Although such a classification is not acceptable today, the word *electric*, from the Greek *elektron*, has been handed down and is still commonly used. If a piece of amber is rubbed, it is said to be *electrified*, or *charged with electricity*, and the invisible force about an electrified piece of amber is called an *electrical force*.

In 1733, a Frenchman named DuFay observed that when a piece of glass is rubbed with cat's fur, both the glass and the cat's fur become electrified but that the glass will attract some charged objects that are repelled by the cat's fur and vice versa. From this observation, he concluded correctly that *there are two exactly opposite kinds of electricity.*

Benjamin Franklin introduced the terms *positive* (+) and *negative* (−) into the science in order to distinguish between the two different kinds of electricity. Franklin defined a positively charged body as one that exhibits the same kind of charge as that associated with a piece of glass after it is rubbed with silk. He defined a negatively charged body as one that exhibits the same kind of charge as that associated with a rubber rod after it is rubbed with cat's fur. He defined as electrically neutral all bodies that exhibit no charge. Further study and experimentation since Franklin's time has added much information regarding the characteristics of electric charges and electric forces.

Attraction and Repulsion

The forces of attraction and repulsion between electrically charged bodies may be demonstrated in the following manner. One end of a rubber rod is rubbed with fur and then suspended by a piece of string (fig. 1A). When a second rubber rod has been elecrified the same way and its charged end brought near the charged end of the suspended rod, the latter turns away (fig. 1A), showing repulsion. If the fur is brought near the charged end of the suspended rod instead of the second rod, the latter turns near the fur (fig. 1B). If a glass rod that has been rubbed with silk is brought near the charged end of the suspended rod, there is attraction (fig. 1C). When the silk is used, however, there is repulsion (fig. 1D). Since the fur and the glass both attract, these have the same kind of electricity and are said to be positively charged. The rubber and silk are said to be negatively charged. This experiment shows that two kinds of charges of electricity exist. It also demonstrates a rule concerning the action of one kind of charge on another.

Figure 1A shows that two negative charges repel each other. Figure 1C shows that positive and negative charges attract each other, and figure 1E shows that two positive charges repel each other. This attraction or repulsion is mutual and is expressed in the following fundamental laws.

1. **Like charges repel each other,** or the force between two like charges is one of *mutual repulsion.*
2. **Unlike charges attract each other,** or the force between two unlike charges is one of *mutual attraction.*

3. The force of attraction or repulsion between two electrical charges varies directly with the product of the quantities of the charges and inversely with the square of the distance between them.

Note the similarities between the laws of electricity and the laws of magnetism.

For a long time it was believed that only substances such as amber, glass, wax, silk, and cat's fur were capable of being electrified. It is now known that under the proper conditions *any* substance can be charged electrically. That is, all substances possess the property of electrification. The question then arises: if all substances are capable of being electrified, how is electrification related to matter? The answer to this question is to be found in the study of the structure of matter.

Structure of Matter

Matter may be defined as any substance that has weight (mass) and occupies space. Examples of matter are air, water, cars, clothing, and our own bodies. From these examples, it can be concluded that matter may be found in any one of three states—namely, solid, liquid, or gaseous. (Plasma, an ionized gas, is considered as a fourth state of matter by some authorities.)

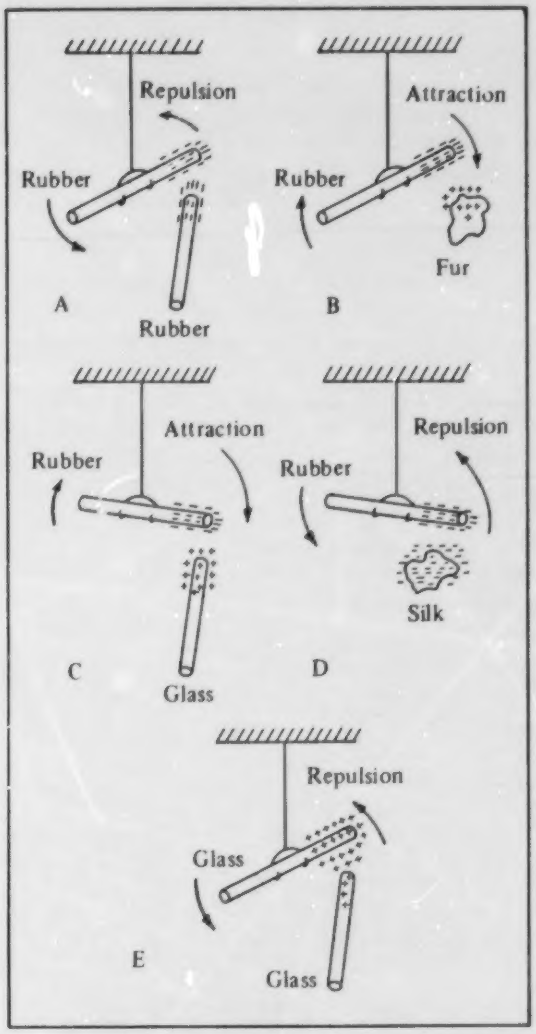


Fig. 1. Attraction and repulsion of charged bodies

All matter consists of one or more basic materials that are called **elements.** Scientists have definite proof that 103 elements exist and believe that there are several others. In chemistry, an element is defined as a substance that can be neither decomposed (broken up into a number of substances) by ordinary chemical changes or made by chemical union of a number of substances. Copper, iron, aluminum, and gold are examples of metallic elements. Oxygen, hydrogen, and sulfur are nonmetallic elements.

A substance made up of more than one element and having properties different from the elements that make it up is called a **compound.** For example, water is made up of two parts hydrogen and one part oxygen. Therefore, water is a compound.

Molecules

A molecule is defined as the smallest particle of matter that can exist by itself and still retain all the properties of the original substance. If a drop of water is divided until the smallest particle possible has been obtained, that particle is known as a molecule. An idea of the size of molecules may be obtained by imagining that a stone is first broken into two pieces, that the two pieces are then broken into four pieces, and that this process is carried on indefinitely. The smallest particle of stone that could be obtained by this process would be a molecule. Actually, it is impossible to crush a stone into its molecules. We can only crush it to dust. One small particle of dust is composed of thousands of molecules.

Atoms

An atom is defined as the smallest part of an element that can take part in ordinary chemical changes. The atoms of a particular element are of the same average mass, but their average mass differs from that of the atoms of all other elements. For simplicity the atom may be considered to be the smallest particle that retains its identity as part of the element from which it is divided.

Figure 2 shows that a molecule of water is made up of two atoms of

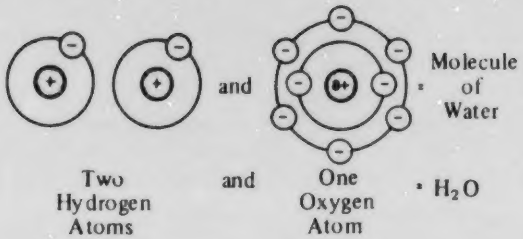


Fig. 2. Molecule of water

hydrogen and one of oxygen. Since most periodic tables list 103 elements, there must be 103 different atoms, or a *different* atom for each element. All substances are made of one or more of these atoms. Just as thousands of words can be made by combining the proper letters of the alphabet, so thousands of different materials can be made by chemically combining the proper atoms.

The individual atom was formerly invisible and hypothetical, but scientists have viewed and photographed single uranium and thorium atoms studding large organic molecules. This was done with a scanning electron microscope, and magnification was about one million times. The heavy metal atoms in the molecules showed up as bright dots against a gray background, but the smaller connecting atoms, primarily carbon, could not be seen. In other words, all of the other atoms of the elements still remain invisible. However, the fact that they are invisible does not prevent a knowledge of the characteristics of such tiny bits of matter. In fact, many familiar things are also invisible. For example, no one has ever seen the wind. Yet, its existence is known because of associated visible effects such as an unfurled flag, the movement of grass and leaves, and the presence of whitecaps on the sea. By experiment and study, scientists have been able to learn facts about the atom and, from these facts, have been able to give an understandable explanation of the makeup of the atom.

The Electron Theory

Although it was formerly believed that the atom was the smallest particle of matter, it became evident from scientific experiments that an atom contains numerous particles. Electrons, protons, and neutrons are the particles of primary interest in this discussion. Any atom contains a nucleus around which one or more electrons revolve in elliptical orbits, similar to the way the planets revolve around the sun in our solar system. Figure 3A shows the atomic structure of the simplest of all atoms, the hydrogen atom. It has one electron revolving around one proton that acts as a nucleus. The nucleus of a helium atom (fig. 3B) has two protons (2P) and two neutrons (2N) around which two electrons revolve in orbits.

Notice that the electrons are marked with a negative sign (−) and the protons with a positive sign (+). The neutrons of an atom do not have an electrical charge. The charge on an electron was first measured by R. A. Millikan, an American physicist, and it was arbitrarily called a negative charge. Thus, electrons are considered negative, and protons are considered positive. The electrical charge on a proton is exactly equal and opposite to that of the electron. Therefore, both the hydrogen atom and the helium atom shown in figure 3 are electrically balanced because they have an equal number of positive and negative charges, or an equal number of electrons and protons.

The mass, size, and electrical charge on any electron is the same as that of any other electron, and the mass, size, and electrical charge on any proton is the same as that of any other proton. Because it is believed that no smaller amount of electricity exists, the charge on the electron is the elemental unit of electricity. However, a much larger unit of charge, called a *coulomb*, is commonly used because the elemental unit is too small a quantity of electricity for practical purposes. One coulomb of electricity contains over 6 million, million, million (6.24×10^{18}) electrons. Electrons and protons are approximately spherical particles of matter. The diameter of an electron, approximately 0.00000000000022 inch, is about three times the diameter of a proton. Despite its smaller diameter, a proton has a mass 1,850 times greater than the mass of an electron. In other words, a proton is 1,850 times heavier in respect to an electron in an atom.

Sir Isaac Newton, an English physicist, experimented with gravity and developed the law that stated that every object attracts every other object with a force that is directly proportional to the product of their masses and inversely proportional to the square of distance between them. This is called Newton's Law of Gravitation.

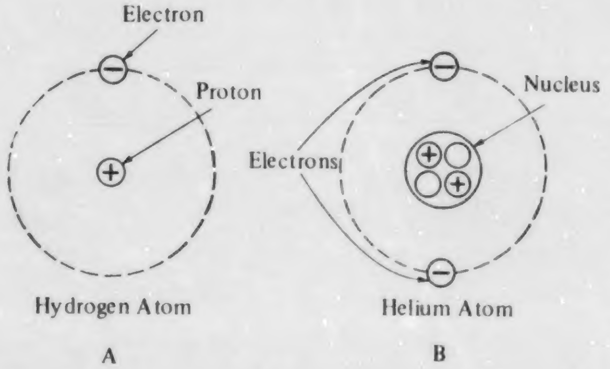


Fig. 3. Structure of the hydrogen and helium atoms

Notice the similarity between this law and the law of attraction of charged bodies. It is gravitation that holds the universe together. With no gravitational field, the planets would not revolve around the sun in their orbits but would fly off at a tangent. The moon would cease to revolve around the earth, and, because of the rotation of the earth, objects on the surface of the earth would be thrown into space like mud from a bicycle wheel.

The force of gravity is believed to be small in comparison to the electric, magnetic, and nuclear forces within the atom, but it acts on the particles composing the atom in the same way that it acts on the planets in the solar system. That is, it helps the other forces keep the electrons, which revolve at tremendous speeds around the nucleus, in their orbits. Even though the electrons and the protons have attracting unlike electrical charges, centrifugal force prevents the electrons from moving directly to the nucleus of the atom. The electrons also spin on their axes just as the earth rotates on its axis.

Atoms of other elements are more complex than the hydrogen and helium atoms. Figure 4A represents the structure of the carbon atom. Notice that six orbital electrons revolve in two separate rings or shells around the nucleus, which contains six protons and six neutrons. Figure 4B shows the atomic structure of an aluminum atom. Its nucleus has thirteen protons and fourteen neutrons around which thirteen electrons revolve in three separate rings, or shells. Twenty-nine electrons revolve in four separate shells around the nucleus of the copper atom shown in figure 4C.

The electron theory states that the only difference between the various elements is the number and arrangement of the electrons, protons, and neutrons of which each atom is composed. The electrons of an atom have a definite order to their arrangement. The maximum number of electrons that can be contained in a particular orbital shell of an atom can be determined by multiplying the square of the number of the shell by two. For example, shell no. 1 can hold $2 \times 1^2 = 2$ electrons; shell no. 2 can hold $2 \times 2^2 = 2 \times 4 = 8$ electrons; shell no. 3 can hold $2 \times 3^2 = 2 \times 9 = 18$ electrons; and shell no. 4 can hold $2 \times 4^2 = 2 \times 16 = 32$ electrons. Atoms of the known elements have as many as seven shells in which electrons revolve. None of these shells can hold more than thirty-two electrons because of a rule in electron theory that states that the outer shell of an atom will

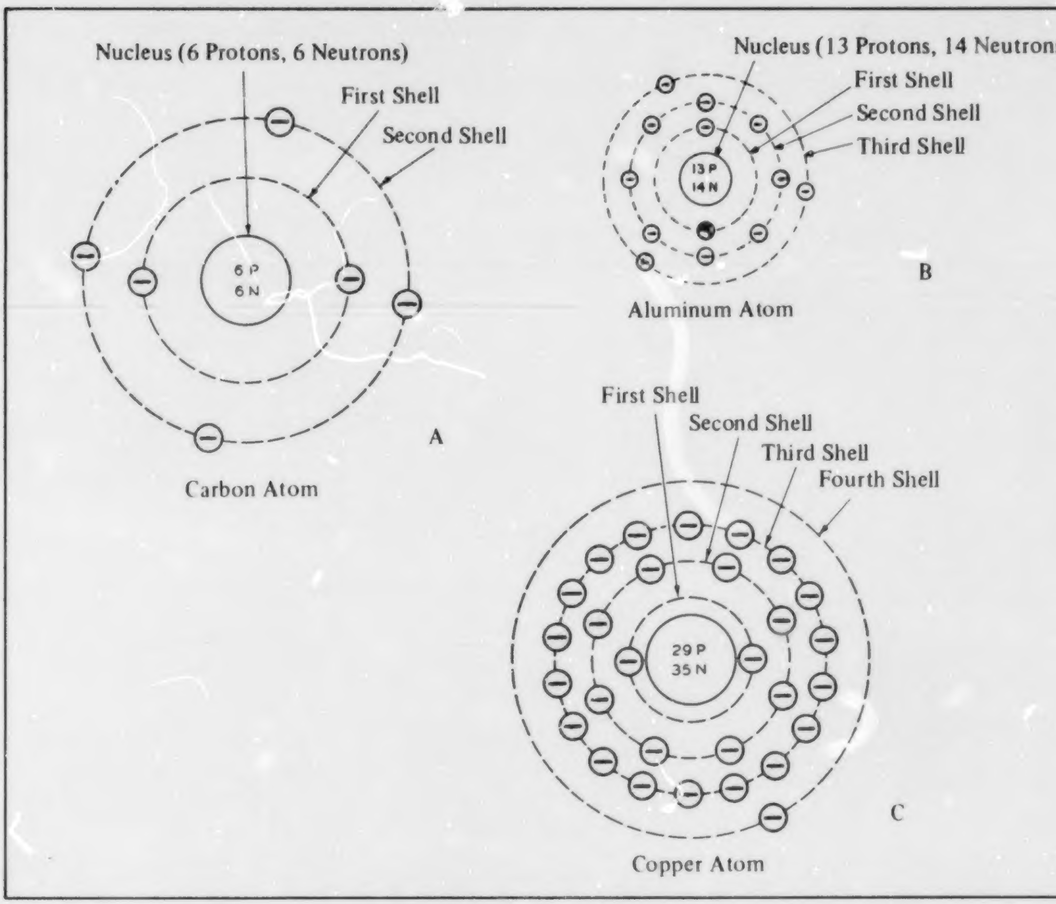


Fig. 4. Structure of the carbon, aluminum, and copper atoms

have no more than eight electrons. Although shells three through seven can each hold more than eight electrons, none of these shells will take more than eight electrons before the next outer shell is started. For example, consider an atom that has eight electrons revolving in its outer orbital shell. The next electron that is added to the atom will start a new outer orbital shell, even though the former shell may eventually hold many more than eight electrons.

The electrons that revolve in the outer shell, called the *valence shell*, are the ones of primary interest in this discussion. The attracting influence of the positive nucleus of an atom weakens with distance. For this reason, the electrons that revolve in the valence shell are easier to move out of their orbits than the ones in the inner shells. They are the ones that are used to operate electrical and electronic apparatus. The electrons that revolve in the inner shells are called *planetary electrons*.

Conductors

If enough energy is added to the centrifugal force of an electron, the electron will leave its orbit and move into a higher orbit. Since a valence electron has no higher orbit, it will *be freed* from its atom and move into another atom. If enough energy or force is applied to a closed circuit, the valence electrons in the atoms of the material will simultaneously flow or drift from atom to atom through the material. The energy applied to the valence shell of an atom is distributed among the electrons in the shell. For this reason, the elements that have only one valence electron are the best electrical conductors because less energy is required to move the electron out of its orbit.

Gold, silver, and copper atoms each have only one valence electron. Gold is the best conductor because a gold atom has six shells and its valence electron is farther from its nucleus. Thus, the nucleus of the atom has less influence on its valence electron. Silver is the next best conductor with five shells. Copper, however, is used most because it is less expensive.

Aluminum is not a very good conductor because an aluminum atom has three valence electrons. However, it is used as a conductor where weight is a major consideration, such as in cross-country, high-tension lines with long spans between supports. Usually these are stranded cables that have a small steel wire core to provide the necessary tensile strength.

The ability of a material to conduct electricity depends also on its dimensions. In other words, the ability of a conductor to carry electricity will vary directly with the area of its cross section. More atoms are present in a large cross section, and therefore more free electrons are available. Conductors may be in the form of bars, tubes, sheets, or wire. Many sizes of wire, from the fine hairlike wire used in coils of sensitive measuring instruments to large cables used to carry high currents in electric power-generating plants, are in use today. Stranded wire is used when flexibility is necessary, such as in the cords of lamps, electric irons, and toasters.

Insulators

Electrical conductors must be protected and isolated by materials called insulators (also known as *dielectrics*). No known material is a perfect insulator through which electricity cannot be forced, but some materials are such poor conductors that for all practical purposes they are classified as insulators. Glass, mica, porcelain, air, dry wood, rubber, oil, cotton, insulating varnish or enamel, and certain plastics such as polystyrene are insulators.

Neon, argon, krypton, helium, xenon, and radon are the six naturally stable elements. The atom of a stable element contains eight electrons in its valence shell (a full shell). Such an atom will not combine with other atoms to form compounds. Atoms that have fewer than eight valence electrons tend to stabilize. If the valence shell is less than half filled, an atom tends to empty its valence shell by giving up its valence electrons (conductor). If the valence shell is more than half filled, an atom tends to fill its valence shell by collecting electrons. Materials that have these kinds of atoms are classified as insulators. For example, an oxygen atom is a good insulator because it has six valence electrons and it tends to fill its valence shell by collecting electrons from atoms that tend to empty their valence shells. Since a hydrogen atom has one valence electron, it tends to empty its valence shell. When a hydrogen atom is close enough, it will share its valence electron with an oxygen atom. This action bonds the two atoms together. A molecule of pure water is formed when two hydrogen atoms combine with one oxygen atom. Since the valence shell of the oxygen atom is completely filled (eight electrons), the molecule of pure water is stable and is a good insulator.

Even though the molecules of insulators are fairly stable, some of them will give up electrons under certain conditions. For example, glass will become positively charged and silk will become negatively charged when the glass is rubbed with silk. Under this condition, the glass gives up electrons to the silk because of the heat generated by the friction of rubbing. This phenomenon is not completely understood (apparently silk has a greater tendency to collect electrons than does glass), but it is thought that the surface atoms of a material have some free electrons because they cannot combine with other atoms as they do inside the material.

Electrical Production

Since the glass lost the same number of electrons that was gained by the silk, the electric charges on the materials are equal, but their polarities are opposite. Thus, the two kinds of electricity in normal matter can be separated by the means of *work*. When this happens, some of the atoms in both materials are unbalanced electrically. The unbalanced atoms in the glass are called *positive ions* because they have a deficiency of electrons. The positive protons outnumber the negative electrons in such an atom. The unbalanced atoms in the silk are called *negative ions* because they have an excessive number of electrons. The electrons outnumber the protons in such an atom. The materials will hold their charge if they can be isolated. In an isolated condition, the electric fields are static (static electricity). When a conducting path is provided between a charged material and a neutral material (or one that has an opposing charge), electrons will flow (current electricity) from one material into the other until the electric charge between the materials is near zero. The force that causes electrons to flow is called *electromotive force* (emf).

The heat caused by the friction of rubbing two dissimilar materials together will produce electric charges on the materials because temperature affects the surface electrons in the atoms of the materials. When heat is applied to the welded junction point of two dissimilar metals, such as platinum and constantan or copper and zinc, electrons will be driven from one metal into the other if a complete circuit is formed. The temperature at the junction may be read from the dial of a calibrated electrical meter connected in the circuit because the rate of intensity of the electron flow is governed by the amount of heat applied to the junction.

The common automobile battery is a good example of an electrochemistry method of producing electricity. This method depends on the reaction of certain dissimilar metals such as copper and zinc with a solution of water and sulfuric acid. When pressure is applied in the proper direction to certain crystals, such as quartz, some of the electrons in the atoms of the material are forced out of their orbits. These free electrons can be used as an electrical current flow by forming a circuit from one side of the crystal to the other side.

The "magnetoelectricity" method of producing electricity is the one of primary interest here. An electrical current will flow in a conductor of a completed circuit when the conductor "cuts" magnetic lines of force. When an electrical current flows in a conductor, magnetic lines of force are "set up" around the conductor (electromagnetism). It becomes apparent that magnetism and electricity are related since one can be used to produce the other. These methods will be discussed later.

Exercise

1. What are the two kinds of electricity?
2. How do positive and negative charges affect each other?
3. How does electrical force differ from magnetic force?
4. Explain the statement that all substances possess the property of electrification.
5. What is a *molecule?*
6. What is an *atom?*
7. What particles does an atom contain?
8. What is the elemental unit of electricity?
9. Which electrons in an atom are used to operate electrical apparatus?
10. Which elements are the best electrical conductors, and why?
11. How is *current electricity* produced?
12. Define *electromotive force* (emf).

E-3

Electromagnetism

Objectives: After completing this assignment, you will be able to—

1. discuss what affects the strength and polarity of an electromagnet;
2. tell what is required to produce a magnetic flux;
3. compare a moving electric field and a moving magnetic field; and
4. define *solenoid* and *electromagnet*.

The Magnetic Field

In 1819, Hans Christian Oersted, a professor of physics at the University of Copenhagen in Denmark, discovered a direct connection between electricity and magnetism. Before this time, Oersted had believed, and thought he had proved, that no connection between these two basic forces existed. His usual custom was to connect a wire conductor to a voltaic cell and then place it at right angles to, and directly over, a compass needle. In this position, the compass needle did not move.

However, one day, while discussing the experiment with his students, he accidentally placed the current-carrying conductor parallel to the compass needle. He was amazed when he saw the compass needle turn at right angles to the conductor. This excited his interest so much that he continued his experiments. He found that if the polarity of the electrical current were reversed in the conductor the compass needle would swing at right angles in the other direction, and that if the needle were placed over the conductor the entire action would be reversed.

By these experiments, Oersted proved that a wire carrying a current of electricity has around it a field of force that acts on a compass needle in a manner similar to the field of force around a permanent magnet. Thus, electricity produces magnetism. The operation of today's motors, generators, transformers, magnetic starters, relays, and countless other electrical equipment depends on the application of Oersted's discovery.

Theoretically, the magnetic field of every magnet extends throughout space. Practically, if a compass were moved gradually away from a current-carrying conductor, a point would soon be reached where the effect of the field would no longer be felt and the compass would point to the north pole of the earth. If the current in the conductor were increased, the compass would again point the direction of the magnetic field. This shows that the strength, or intensity, of the magnetic field around a current-carrying conductor increases when the current increases and decreases when the current decreases. Furthermore, the direction of the magnetic field around a current-carrying conductor depends on the direction of the current through the conductor. Reversing the direction of current in the conductor reverses the direction of the magnetic field. The direction of the magnetic field is always at a right angle to the electric field.

A rule, known as the *left-hand rule*, for determining the direction of the magnetic field about a current-carrying conductor may be stated as follows: If the conductor is grasped in the left hand with the thumb pointing in the direction of electron current flow, the fingers will point in the direction of the magnetic field (see fig. 1).

The magnetic fields produced by

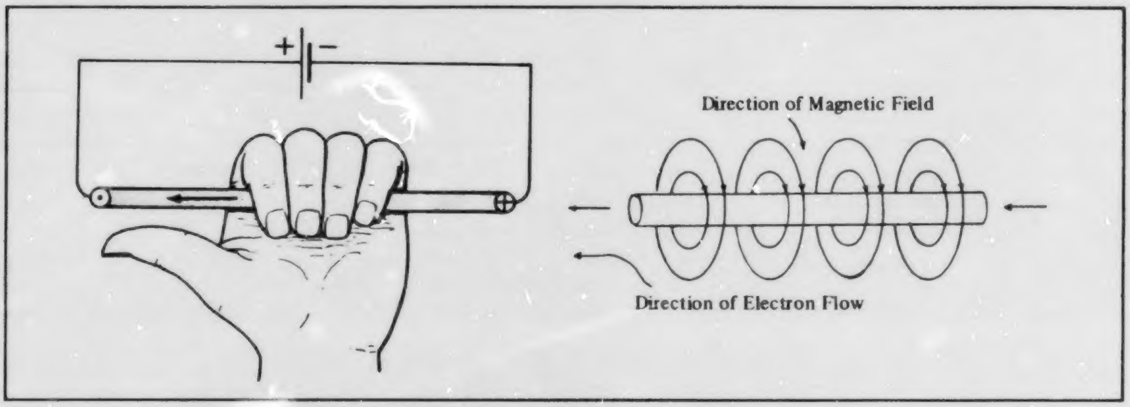


Fig. 1. Left-hand rule for determining the direction of the magnetic field

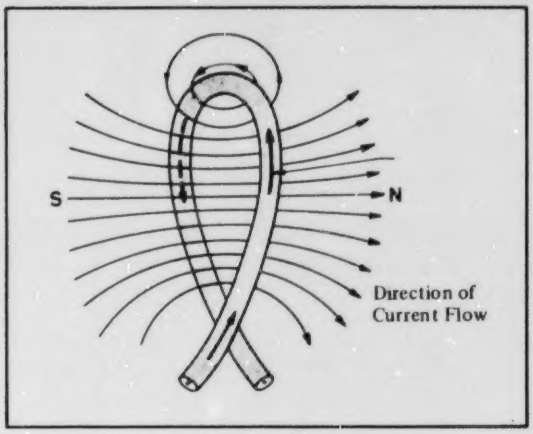


Fig. 2. Magnetic field of a looped conductor

electric currents in conductors cause attraction or repulsion, depending on the direction of current flow. Parallel currents flowing in conductors in the same direction cause magnetic attraction. In other words, the magnetic lines of force set up by the currents tend to encircle the conductors like rubber bands so that the conductors are attracted to one another. Parallel currents flowing in the opposite direction set up magnetic fields that oppose one another so that the conductors are repulsed by one another. Currents flowing through conductors that make an angle with one another produce magnetic fields that tend to force the conductors into parallel paths with their current flowing in the same direction.

If a conductor were bent in the form of a loop, the same circular lines of force, or magnetic field, would surround the conductor as when it was straight. However, all the lines of force would enter on one side (face) of the loop and leave on the other side (face) of the loop, as shown in figure 2. In accordance with the left-hand rule, a north magnetic pole is created on one face of the loop and a south magnetic pole on the other face of the loop.

If several loops of wire were wound to form a coil, it would be called a *helix* or *solenoid*. A helix is actually any coil or wire that is carrying a current, while a solenoid is a coil that has considerable length as compared with its diameter. Figure 3A shows a solenoid wound loosely. Since the current is flowing through each turn in the same direction, the effect of the magnetic field produced is similar to that of parallel conductors (fig. 3A).

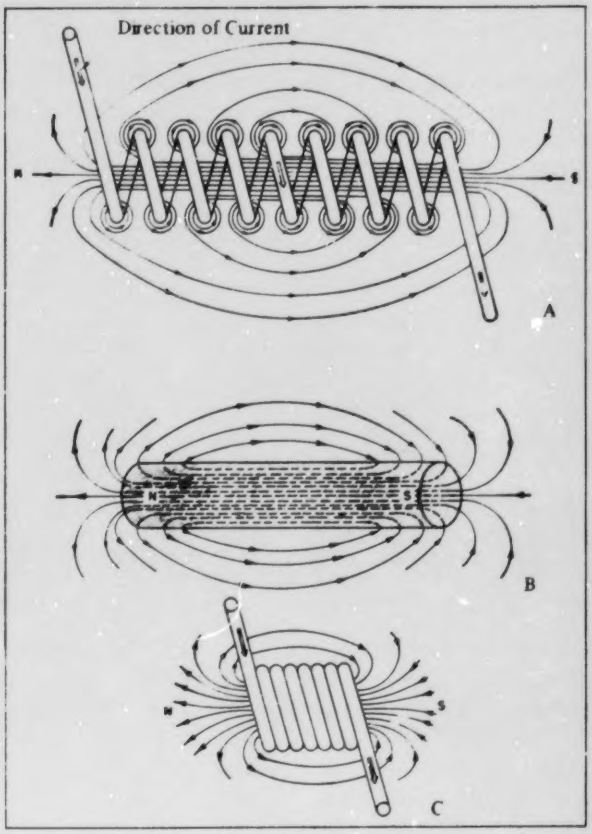


Fig. 3. Magnetic field about a solenoid

Thus, the field is weakened because of the opposition of the flux between the turns, causing some of the lines of force to encircle several turns of the entire coil. Those lines of force produce a magnetic field similar to the magnetic field of a bar magnet (fig. 3B), making a north pole at one end of the coil and a south pole at the other end. Now as the coils are pushed as close together as possible, a great many more lines will encircle the entire coil. Obviously the field within the coil and at the poles is much stronger than the field shown in figure 3A, since practically all the lines of force that previously encircled the individual loops will now encircle the entire solenoid. Therefore, while current is flowing, the solenoid has the properties of a permanent magnet.

The left-hand rule can be applied to solenoids. However, the thumb will point in the direction of the north magnetic pole of the solenoid and the fingers will point in the direction of electron current flow.

If a piece of magnetic material, usually soft iron, is placed within a solenoid through which current is flowing, the magnetic properties of the solenoid are tremendously increased. The reason is that soft iron is more permeable than air and therefore provides a better path for the lines of force (flux) than does air. The inside of any coil is considered as the core whether it is air or some magnetic material. If the coil is wound on a core of magnetic material, it is called an *electromagnet* (fig. 4A). The coil may be wound with one or more layers of wire from one end to the other and back, providing, of course, that the current flows around the core continuously in the same direction. The left-hand rule is also used to determine the polarity of an electromagnet.

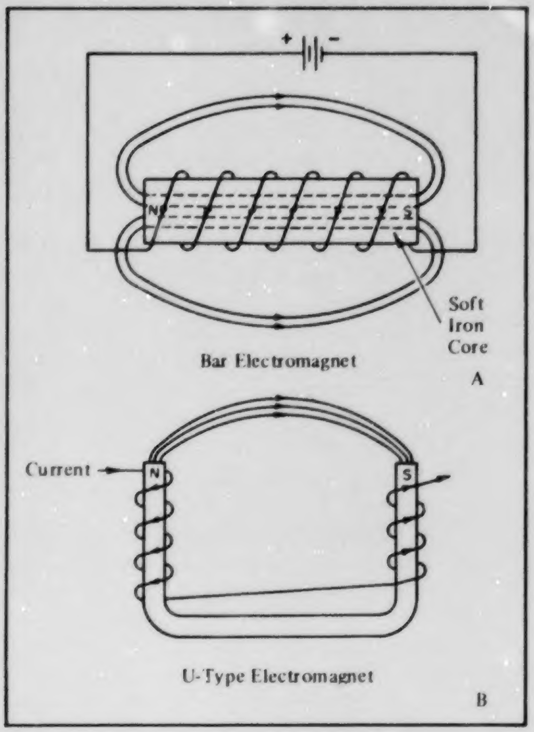


Fig. 4. Types of electromagnets

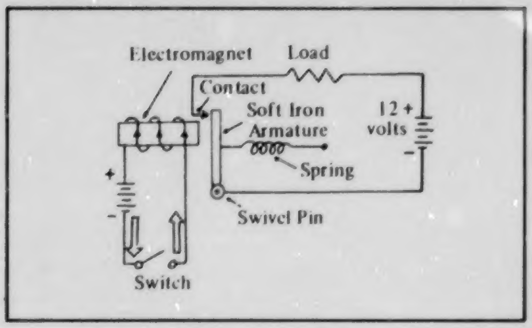


Fig. 5. Simple relay

Any magnetic material may be used as the core for an electromagnet. However, soft iron or soft steel generally is used because the retentivity of those materials is so low that they retain very little residual magnetism when the current stops flowing. This is a very important quality of electrical equipment such as relays. On the other hand, a piece of hard steel when inserted into a coil in which current is flowing becomes a permanent magnet. That is, because of its retentivity, it will retain a large amount of residual magnetism when the current ceases to flow. Electromagnets are widely used in electronic equipment, including relays, motors, generators, radios, and transformers. The U-type electromagnet shown in figure 4B is used in the receiver of a telephone.

The circuit of a simple relay is shown in figure 5. When the switch is closed, current flows through the coil of the electromagnet and is said to *energize* it. That is, it becomes a magnet, and the magnetic field attracts the soft iron armature and overcomes the pull of the spring so that the armature is drawn up against the contact. When the contact is closed, it completes the circuit through the load and the 12-volt battery, and current flows. The current will flow from the negative terminal of this battery through the armature and the load back to the positive terminal of the battery. When the switch is opened, the current flow through the electromagnet stops and is said to become de-energized. Since the magnetic field disappears, the armature is pulled away from the contact by the spring, breaking the circuit and removing the power from the load.

The Magnetic Circuit

The laws that apply to the magnetic circuit are similar to (but not the same as) those of the electric circuit. It has previously been shown that magnetic flux forms closed loops. The path that the flux takes, whether through air or through metal, is called the magnetic circuit. The magnetic circuit will now be compared with the electric circuit.

In order to produce an electric current, a voltage, known as the electromotive force, is required. Similarly, in order to produce a magnetic flux, a force known as the *magnetomotive force* is required. In an electric circuit, for a given electromotive force, the current depends on the amount of resistance. Likewise, in a magnetic circuit, for a given magnetomotive force, the flux depends on the amount of opposition (reluctance). In the magnetic circuit, as in the electric circuit, the relationship expressed in the following statement is true: The result produced is directly proportional to the force that produces it and inversely proportional to the opposition encountered. For the electric circuit, the law states:

$$\text{current} = \frac{\text{electromotive force}}{\text{resistance}}$$

For the magnetic circuit, a similar law may be stated:

$$\text{flux (lines of force)} = \frac{\text{magnetomotive force (mmf)}}{\text{reluctance}}$$

Using symbols instead of words, the following formula may be written:

$$\theta = F/R$$

Where: θ = flux
F = mmf, in gilberts
R = reluctance, in oersteds or rels

If F is expressed in ampere-turns, R is usually in rels. Ampere-turns may be changed to gilberts by multiplying by 1.26, which gives R in oersteds.

There are important differences in the relationship of the electric circuit to the magnetic circuit.

1. In the electric circuit, the resistance is a constant and can be determined by the ratio of voltage to current (discounting the heating effect). In a magnetic circuit, however, the reluct-

ance is not a constant but depends on the flux (strength of the field).

2. In electric circuits, current actually flows (electron flow) from one point to another. In the magnetic circuit, there is not actual flow of flux but merely an indication of the intensity and direction of the magnetic field.

Magnetomotive Force

The magnetizing force set up because of current flowing in a coil or solenoid is known as the magnetomotive force (mmf). Since the strength of the magnetic field about a conductor increases when the current through the conductor increases, the magnetic field about a coil or solenoid will also increase when the current through the coil is increased. In fact, for any coil, if the current is doubled, the strength of the field will also double. Also, since the total magnetic field about a coil is a summation of the field of the individual loops or coils, if the number of loops is increased, the strength of the magnetic field will increase. Therefore, the amount of flux (lines of force) about a helix, whether it has an air core or an iron core, is proportional to two factors: (1) the current in amperes flowing in the coil and (2) the number of loops or *turns* in the coil.

The word *turn* means just one wrap of a conductor around a core (fig. 6), which may be either air for a solenoid or, in the case of an electromagnet, a piece of soft iron. The magnetomotive force is proportional to the current (in amperes) in the circuit and to the number of turns in the coil.

Magnetization Curves

In order to simplify magnetic circuit computations, magnetization curves (also known as *B-H curves*) of certain materials have been prepared (fig. 7). The magnetomotive force, expressed in ampere-turns per inch, is plotted against the flux density (lines of force per square inch). The curve shows that when the magnetomotive force is 20 ampere-turns, the flux density is about 95,000 lines of force per square inch. When the magnetomotive force is increased from 20 to 40 ampere-turns per inch, the flux density increases from 95,000 to about 108,000 lines of force per square inch.

As the ampere-turns per inch continue to increase, the flux density also increases but at a lesser rate. For instance, 40 ampere-turns per inch produce 108,000 lines of force per square inch, but 160 ampere-turns (or four times as much) only produce 120,000 lines of force per square inch.

Thus, a magnetization curve provides a quick and simple method of calculating flux density if the type of core and magnetomotive force in ampere-turns per inch is known. Of course, other magnetic substances do not follow the same magnetization curve as that of annealed sheet steel. In fact, a new magnetization curve must be made for every type of magnetic substance, for no two curves will be exactly alike.

The point where the curve begins to flatten out is called the *knee* of the magnetization curve (fig. 7). This point is also called the *saturation point* since beyond this point it becomes increasingly difficult to increase the flux density. In radio circuits, it is usually desirable that the flux density remain below the knee so that a change in the magnetomotive force will produce a more or less proportional change in the flux density.

Hysteresis Loss

Hysteresis is a lagging of the magnetizing effect behind the magnetizing cause. This phenomenon will be explained with the aid of figure 8. If a constantly increasing magnetizing force (ampere-turns per inch) is applied to a core that has not been magnetized previously, the magnetization curve A–B shows how the flux density increases. If, at point B, the magnetizing current is reduced, the core will start to lose its magnetism, as shown by curve B–C. The flux density becomes smaller as the magnetomotive force is reduced until point C is reached when the magnetomotive force is 0. Note that the flux density at

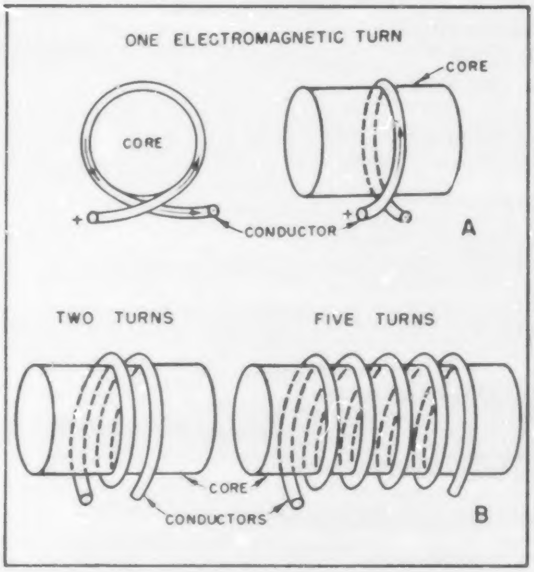


Fig. 6. Electromagnetic turns

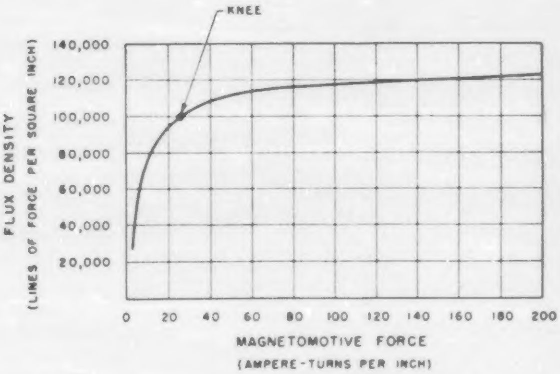


Fig. 7. Magnetization curve for annealed sheet steel

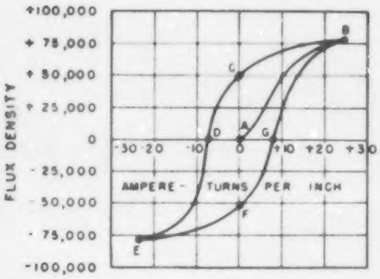


Fig. 8. Typical hysteresis loop or magnetic cycle

point C is 50,000 even though there is no applied magnetomotive force. This *lagging*, or *hysteresis*, is due to the residual magnetism remaining in the core.

If a negative magnetomotive force is then applied, by reversing the direction of the current, the core will lose its magnetism, as shown by curve C–D. It is evident that 8 ampere-turns of negative magnetomotive force are required to completely demagnetize the iron at point D. These 8 ampere-turns of magnetomotive force, which are necessary to overcome the residual magnetism, represent a distinct loss of power and are referred to as *hysteresis loss*.

If the negative magnetomotive force is then increased beyond D to a numerical value equal to the positive value at B, the core will become magnetized in the opposite direction, as shown by curve D–E. The flux density at E will then be equal to the flux density at B.

If the negative magnetomotive force is then decreased to 0, the flux density will vary according to the curve E–F. At point F the magnetizing force is 0. The flux density, because of residual magnetism, is −50,000. The minus sign merely indicates that the direction of the field at point F is opposite to the direction of the field at point C.

If a positive magnetomotive force is then applied and gradually increased, the core will lose its magnetism along curve F–G, become completely demagnetized at point G, and become magnetized again in the opposite direction along curve G–B. This completes the hysteresis loop.

It can be shown that the area within the hysteresis loop is proportional to the amount of work done against the residual magnetism. The energy or power thus lost (hysteresis loss) is considerable and is transformed into heat in the core. The hysteresis loss is therefore an important factor in the design of iron core transformers in which the direction of the flux is continually reversed. A hysteresis loop of small area means a relatively small hysteresis loss, while a loop of large area indicates a large loss.

Relationship of Electric and Magnetic Fields

Up to now, electromagnetism has been attributed to the flow of current in a conductor. However, current flow also means charges in motion. It follows, therefore, that electromagnetism is the result of charges in motion and that a charge moving with respect to the observer is always accompanied by a magnetic field. This fact can be verified by the following experiment.

1. Suppose that several pieces of tinfoil are fastened to the outer edge of a round glass disk and the tinfoil is then charged with negative electricity. That is, each piece of tinfoil is touched by a previously charged negative body (fig. 9A). The negative charges on the tinfoil are represented by the electrons. If the glass disk is then rotated, these electrons will also be rotated (see fig. 9B).
2. If a compass is then held above the rotating electrons, it will be deflected, thus showing the presence of a magnetic field. By placing the compass in various positions, the magnetic field about the rotating electrons will be as shown in figure 9C. Note that this field is the same as that about a wire carrying current (fig. 9D).

The above experiment shows that *a charge in motion produces a magnetic field*. This is one of the most important of the fundamental laws of electricity. It is the basis upon which rest the operation of generators and the production of radio waves.

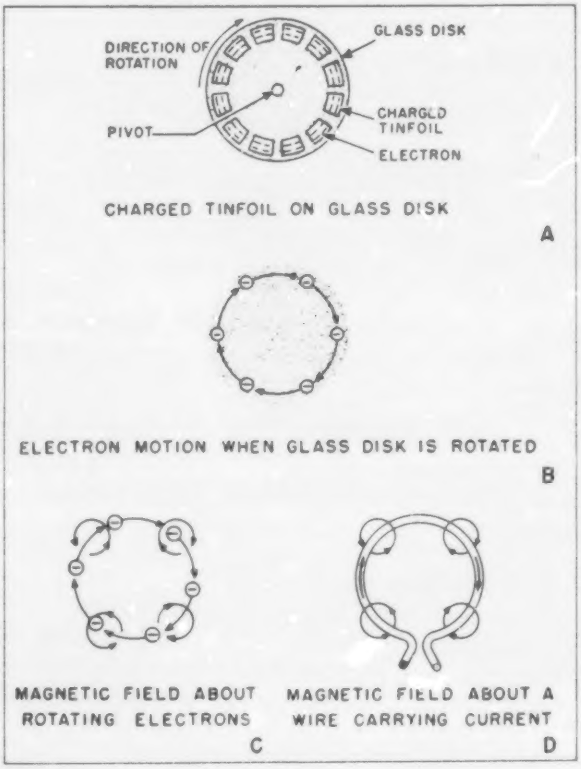

DIRECTION OF ROTATION
GLASS DISK
PIVOT
CHARGED TINFOIL
ELECTRON
CHARGED TINFOIL ON GLASS DISK
A
ELECTRON MOTION WHEN GLASS DISK IS ROTATED
B
MAGNETIC FIELD ABOUT ROTATING ELECTRONS
C
MAGNETIC FIELD ABOUT A WIRE CARRYING CURRENT
D

Fig. 9. Electrons in motion produce an electric field.

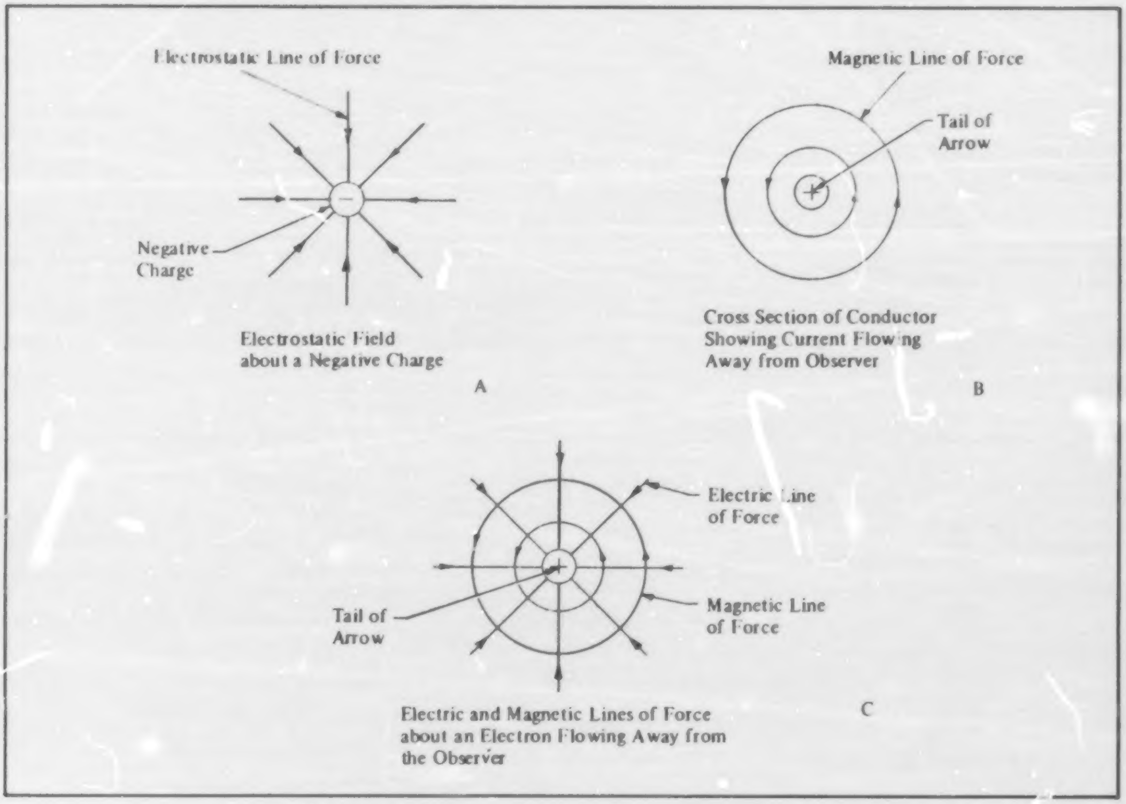

Electrostatic Line of Force
Negative Charge
Electrostatic Field about a Negative Charge
A
Magnetic Line of Force
Tail of Arrow
Cross Section of Conductor Showing Current Flowing Away from Observer
B
Electric Line of Force
Magnetic Line of Force
Tail of Arrow
Electric and Magnetic Lines of Force about an Electron Flowing Away from the Observer
C

Fig. 10. Electric and magnetic lines of force

The fact that a charge in motion produces a magnetic field leads to some very important conclusions. It will be recalled that an electric field exists in the space about a positive or negative charge. Therefore, when a charge is moved, its electric field moves with it, since the two are inseparable. It follows that, instead of a charge in motion, it can be said that an electric field in motion produces a magnetic field. The previous conclusion can then be restated: *a moving electric field creates a magnetic field.* This action is reversible. That is, a moving magnetic field creates an electric field.

The force of the magnetic field acts at right angles to the electric field and also at right angles to the direction in which the charge is moving. This fact is shown in figure 10. The electric field about a negative charge such as an electron is shown in figure 10A. Also, the magnetic field about an electron flowing away from the observer is shown in figure 10B. When both figures are combined, as in figure 10C, the relationship between the electric and magnetic fields about a moving charge can be easily seen. Whenever an electric line of force crosses a magnetic line of force, the two are always perpendicular (at right angles) to each other. Also, the electric and magnetic lines of force are at right angles to the direction in which the charge is moving.

Energy in Magnetic and Electric Fields

When a magnet is moved over iron filings, the magnetic field of the magnet causes the iron filings to move although the iron filings and the magnet are not in contact. Thus, the magnetic field does work on the iron filings. Since the magnetic field has the ability to do work, and since energy is defined as the ability to do work, the magnetic field therefore possesses energy. This energy is appropriately called *magnetic energy.*

Since magnetic fields are created by the motion of charges, the magnetic field is said to represent kinetic energy. This is equivalent to saying that the kinetic energy of an electric current is stored as magnetic energy in the magnetic field the electric current creates.

In practice, all circuits have some amount of resistance, such as the resistance of the wire used for connections, the resistance of the wire of which a coil is made, or the resistance of the resistors in the circuit. Any current flowing through this resistance causes an I^2R power loss, which appears in the form of heat. When power is supplied to a simple circuit that contains resistance, some of the power appears in the form of heat. The remainder of the power becomes the kinetic energy of the current and is stored as magnetic energy in the magnetic field. When the power is removed from the circuit, interrupting the current flow, the magnetic field collapses and returns its energy to the circuit by inducing an emf in it. In other words, it requires energy to establish a magnetic field, and this energy is returned to the circuit when the current stops flowing and the magnetic field collapses.

Just as a magnetic field of force represents energy, so also does an electric field of force represent energy. Remember, if an isolated (or free) electron is placed in an electric field, the electron will be driven from a lower to a higher potential point by the electric field of force. The electric field thus does work on the electron and therefore possesses energy.

Thus, both the magnetic and the electric fields possess energy. The total energy of a moving charge is therefore the sum of the energy in its electric and magnetic fields.

Exercise

1. How will a current-carrying conductor affect the needle of a compass when the compass is brought close to the conductor?
2. What effect would a polarity reversal of the current flow in the conductor in question 1 have on the compass needle?
3. Define *electromagnet*.
4. Define *solenoid*.
5. Why is soft iron or soft steel generally used as the core for an electromagnet?
6. In what equipment are electromagnets widely used?
7. What is required to produce a magnetic flux?
8. What can be concluded about a moving electric field and a moving magnetic field?
9. What makes up the total energy of a moving charge?

Objectives: After completing this assignment, you will be able to—

1. name the units of measurement for electromotive force, current flow, and resistance;
2. write the power law formulas for finding watts, volts, and amperes; and
3. write the formula for calculating efficiency.

E-4

Units of Electrical Measurement

Some electrons, called *planetary electrons*, revolve around the same atom all the time and are very hard to move from one atom to another. Other electrons, called *free electrons*, move about from one electron to another with little or no force applied to them. It is the movement of these free electrons from one atom to another in an organized manner that constitutes current electricity.

A material that has many free electrons is called a *conductor* because it will conduct electricity through it easily. A material that has only planetary electrons is called an *insulator* because it will not permit the flow of electricity through it unless an extremely high force is applied across it. Some good conductors are silver, copper, gold, aluminum, steel, and salt water. Some good insulators are glass, mica, plastic, porcelain, and rubber. Many more in both categories exist.

Even though it is not known for sure what electricity is, many of the things it will do and how to make it do these things are known. Certain measurements are accepted and used, and definite mathematical relationships exist between each of these units of measurement.

If electrons are to move from one atom to another to any great extent in an orderly fashion, there must be a force causing them to move. Since like electrical charges repel each other and unlike charges attract each other, electrons can be caused to move throughout the length of a conductor if they are removed from one end of the conductor and placed on the other end. This causes too many electrons to be on one end and too few on the other. The electrons will be repelled from the end with an excess of electrons and attracted to the end with a need for them.

Electrons have a negative charge. Therefore, the end with the excess of electrons will have a negative potential, and the end with too few electrons will have a positive potential. The potential difference between the two ends causes a force to be exerted on the electrons. This force is called *electromotive force* (emf) and is measured in a unit called a *volt*. If some means for continuously removing the electrons from one end of the conductor and placing them on the other is provided, the electrons will continue to flow through the conductor.

The quantity of electron flow is measured in *coulombs*. A coulomb is 6.24×10^{18} electrons, or 6,240,000,000,000,000,000 electrons. The rate, or *intensity*, of current flow is measured in *amperes* (amp). One ampere is one coulomb per second. As electrons move from one atom to another, they encounter opposition because of the atomic structure of the material. This opposition is called *resistance* and is measured in a unit called an *ohm*. An ohm is the amount of resistance that will permit one volt to push one ampere. The ability to conduct electricity, called *conductance* or *conductivity*, is measured in *mho* and is exactly opposite to resistance.

If the cross-sectional area of a conductor is twice that of another conductor, the larger conductor has a greater ability to conduct electricity (it has a greater number of free electrons). In other words, the conductivity of the larger conductor is greater, and it has less resistance to electrical current flow. For a different viewpoint, the smaller conductor offers more resistance to electrical current flow, and its conductivity is less.

This is not a course in mathematics, but since a definite mathematical relationship exists between all of the units of electrical measurements, the use of mathematics is the easiest and best way to learn the fundamentals of electricity.

Four of the fundamental units of electrical measurements were named after early experimentalists: Andre M. Ampere, a French physicist; Alessandro Volta, an Italian physicist; James Watt, a Scottish inventor and engineer; and Georg Simn Ohm, a German physicist.

Ohm's Law

From facts established earlier and from his own experiments, Georg Simon Ohm found that the ratio of voltage and current for any type of conductor is a constant that depends on the material of which the conductor is made and its physical dimensions. The results of his experiments are called Ohm's law, which can be written mathematically:

$E = I \times R$

Then $I = E/R$

and $R = E/I$

Where: E = electromotive force, or voltage applied across the conductor

I = intensity of current flow, or amperes through the the conductor

R = resistance (in ohms) of the conductor, depending on the material of which the conductor is made, its physical dimensions (length and cross-sectional area), and temperature

Examples:

1. Assume that 100 volts are applied to a circuit in which the resistance to current flow is 10 ohms. Find the current flow in amperes.

$$\text{current} = \frac{\text{voltage}}{\text{resistance}}$$

$$\text{or amperes} = \frac{\text{volts}}{\text{ohms}}$$

$$\text{or } I = \frac{E}{R} = \frac{100}{10} = 10 \text{ amp}$$

2. If the voltage and current are known, the circuit resistance may be found in the same manner. Using the same circuit values, find the resistance in ohms to current flow.

$$\text{resistance} = \frac{\text{voltage}}{\text{current}}$$

$$\text{or ohms} = \frac{\text{volts}}{\text{amperes}}$$

$$\text{or } R = \frac{E}{I} = \frac{100}{10} = 10 \text{ ohms}$$

3. The voltage can be found by multiplying the circuit resistance by the current flow.

$$E = I \times R = 10 \times 10$$
$$= 100 \text{ volts}$$

The voltage across a resistor or any other component is called a *voltage drop* (E_D) and is the potential difference required to produce the current through the part of the circuit under consideration. The formula $E = IR$ may be used to compute the voltage drop (E_D) across any part of a circuit.

The Power Laws

Power is the time rate at which work is done and is measured in foot-pounds per second (ft-lb/sec). Expressed as an equation:

$$\text{power} = \frac{\text{work}}{\text{time}}$$

The following example will serve as an illustration of the difference between work and power. When a 100-pound bag of sand is lifted 10 feet, 1,000 ft-lb of work are performed. If this work is performed in 5 seconds, 200 ft-lb/sec of power are required.

$$\text{power} = \frac{\text{work}}{\text{time}} = \frac{1{,}000 \text{ ft-lb}}{5 \text{ sec}}$$
$$= 200 \text{ ft-lb/sec}$$

Power is also measured in horsepower (hp). One mechanical horsepower equals 550 ft-lb/sec, or 33,000 ft-lb/min.

The watt is the unit of electrical power. One watt of power is required to do one joule of work in one second. Expressed as an equation:

$$\text{watt} = \frac{\text{joule}}{\text{second}}$$

Seven hundred and forty-six (746) watts equal one mechanical horsepower, and one watt equals 0.00134 hp.

Electrical circuits are described in terms of voltage, amperage, and wattage rather than in terms of joules. For this reason, it is more convenient to form an equation that expresses the power in watts in terms of volts and amperes. The power expended in any circuit is the product of voltage and current flowing in that circuit. In other words, one watt of power is being expended between two points when one ampere of current flows between the points under the pressure of one volt. Expressed as an equation:

$P = I \times E$ (think of "pie")

Then $I = P/E$

and $E = P/I$

Where: P = power, in watts

I = intensity of current flow, in amperes

E = electromotive force, in volts

Examples:

1. If an electric motor requires 10 amp at 110 volts, what is the power?

$$P = IE = 10 \times 110$$
$$= 1{,}100 \text{ watts}$$

2. If a battery charger operates at 100 volts and consumes 600 watts, what must be the smallest fuse that will maintain the charger operation?

$$I = P/E = 600/100 = 6 \text{ amp}$$

3. What voltage will be measured at the terminals of a 500-watt generator when 10 amp are being drawn?

$$E = P/I = 500/10 = 50 \text{ volts}$$

The electrical law is sometimes called Watt's law, and W is used to represent power in the formula instead of P. Notice that resistance was not considered in the power law. However, values of resistance may be considered by substituting values from Ohm's law formulas into the power law formula. By substituting the value of I in Ohm's law in terms of voltage and resistance for I in the power law, a formula can be developed to find power if the voltage and resistance are known. For example:

Ohm's law: $I = E/R$

Power law: $P = I \times E = \left(\frac{E}{R}\right) \times E = \frac{E^2}{R}$

The following problem shows an application of the formula. What is the wattage rating of a 120-volt bulb that has a resistance of 144 ohms?

$$P = \frac{E^2}{R} = \frac{120 \times 120}{144}$$
$$= 14{,}400/144 = 100 \text{ watts}$$

By transposing, R can replace P in the formula so that the resistance of a circuit can be determined if the power and voltage are known. For example, a resistor radiates 20 watts of power in the form of heat when connected to a 20-volt DC source. What is the resistance value of the resistor?

$$R = \frac{E^2}{P} = \frac{20 \times 20}{20}$$
$$= 400/20 = 20 \text{ ohms}$$

Another important formula can be developed by substituting the value of voltage (E) in Ohm's law (IR) for the value of voltage in the power law.

$$P = I \times E = I \times (I \times R) = I^2R$$

The most common loss of power in electrical work is that which is dissipated in the form of heat when current flows through a resistance. This power loss is sometimes called the I^2R loss, or copper loss, and is always present when current is flowing. The heat is usually dissipated into the air and lost, but it can be used, as in the case of the electric oven, toaster, and soldering iron. If 0.3 amp of current flows through a resistor, what wattage is expended across the resistor?

$$P = I^2R = 0.3 \times 0.3 \times 20 = 1.8 \text{ watts}$$

Efficiency

Electric motors have losses because of friction and resistance of the windings (I^2R loss). Therefore, the mechanical output can never equal the electrical input, and no machine will ever be 100 percent efficient. The output of any power-consuming device divided by the input and multiplied by 100 will give its power efficiency percentage. *Examples:*

1. If a 1-hp (746 watts) motor draws 6 amp of current at 220 volts, what is the efficiency of the motor?

$$\text{efficiency} = \text{output/input} \times 100 = \frac{746}{220 \times 6} \times 100 = 74{,}600/1{,}320 = 56.51 \text{ percent}$$

2. If 45,000 watts are applied to a motor and its output is found to be 50 hp, what is the efficiency of the motor?

$$\text{efficiency} = \text{output/input} \times 100 = 50 \times 746 \times 100/\ 45{,}000 = 3{,}730{,}000/45{,}000 = 83 \text{ percent}$$

It is sometimes desirable to use either smaller or larger units of measurement. The milliwatt is equal to 0.001 watt, the microwatt is equal to 0.000001 watt, the kilowatt is 1,000 watts, and the megawatt is 1,000,000 watts. The same prefixes can be used with volts, amperes, ohms, and mhos to give the same results.

Exercise

1. What is conductance directly opposite to?
2. How is electromotive force measured?
3. What is the electrical law sometimes called?
4. What kind of charges do electrons have?
5. In what unit is the rate or intensity of current flow measured?
6. What unit is used to measure resistance?
7. Write the electrical power law formula for watts.
8. Write the electrical power law formula for volts.
9. Write the electrical power law formula for amperes.
10. Write the formula for calculating efficiency.

Section

F

Controls

F-1. Switches
F-2. Timers and Solenoids

F-1

Switches

Objectives: After completing this assignment, you will be able to—
1. state the primary function of switches;
2. discuss different types of switches; and
3. describe how to use an ohmmeter to check a switch for continuity.

Appliances such as dishwashers and clothes washers perform a number of different functions. These functions must be performed in the proper order for the machines to operate in the proper mode. Switches are used to start and stop each of these operations. Thus, switches are *control devices* in that they control individual operations. In a sense, every electrical appliance needs at least one control device. If an extension light comes on when you plug the cord in an outlet, the control is plugging it in. Most appliances do have switches to start them, and these switches take a variety of shapes and forms. Appliances which are connected to plumbing also have mechanical switches to start and stop the flow of water, but these mechanical switches are usually controlled electrically.

In an automatic appliance, the master control determines which switches turn on and off. The determination may be based on time or on a physical condition, such as water reaching a suitable level or an oven reaching a desired temperature.

The many different ways to turn on electricity should be considered. The most common is the wall switch used for lighting, which is flicked up or down. Appliances such as food processors have a set of push buttons for selecting the proper motor speed. Push buttons are also used on some types of heaters to select the proper temperature. Heaters also use a tip-over switch that must be held in to allow the electricity to flow. There are switches that you have to hold on to operate the machine. Some appliances have a rotary switch, such as a dishwasher or clothes washer. Some small appliances have a sliding lever, where the amount of movement regulates the speed.

The external form of the switch makes no difference in the operation of the switch. All switches have one thing in common. A switch simply connects two contacts when it is in the *on* position and opens the contacts when it is *off*. If you use an ohmmeter to check continuity across a switch, it would look like an open circuit when it is off and a short circuit when it is on. In figure 1A, the switch is open, and

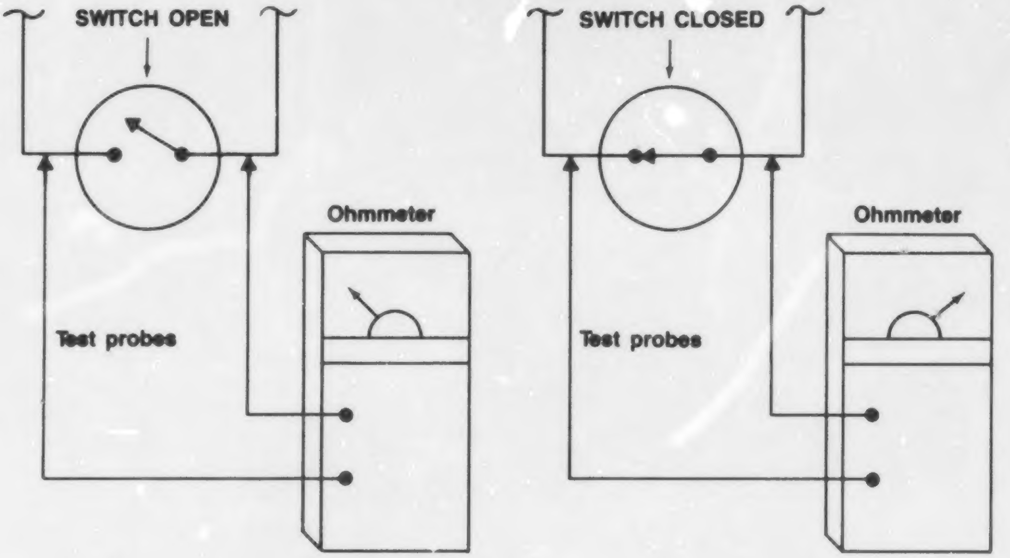


Fig. 1. Continuity check with an ohmmeter

when the ohmmeter probes are placed across it, the meter indicates infinite resistance, which means an open circuit. With the switch closed (fig. 1B), the meter indicates zero ohms, or a short circuit. When checking the continuity of a switch, you must always make sure there is no other continuous path across the switch in the rest of the circuit. In short, disconnect the switch from the circuit before checking it out.

It is common for a switch to fail by sticking in the open or closed position. If this happens, the switch should be replaced. Disconnect all wires going to the switch, noting carefully where each wire is connected, and put in a new switch. Connect the wires to the new switch in the same way they were connected to the old switch. Sometimes, one switch in an assembly of several push-button switches goes bad, and you may have to replace the whole assembly because these switches cannot be separated. Therefore, many wires have to be disconnected and reconnected, and you should make a drawing of the connections before disconnecting a single wire.

A switch that simply makes and breaks one connection is called a *single-pole, single-throw switch.* "Single-pole" refers to the fact that only one wire is connected or disconnected by the switch. "Single-throw" means that there is only one method of connecting this wire. In some of the more complicated switches, one or more wires may be connected at different times to one or more contacts.

For example, in a rotary switch, the wire connected to the rotating contact may be connected to any of several contacts in turn as it is rotated. A single-pole, double-throw switch, which might be used to select a high or low heat in a heating appliance, is shown in figure 2. If the switch is moved to the H contact, only the high heating element is in the circuit. When the L position is selected, only the low element is connected. There are two "on" positions, so "double-throw" is the name of this switch. When you look at the single-throw and double-throw switches, they may appear identical. However, the double-throw has three contacts while the single-throw has only two contacts.

When you need to check a double-throw switch for continuity, you must carefully consider what you are doing and what the rest of the circuit is used for. If you measured the continuity between the H and L contacts shown in figure 2, you would always read the sum of the two heating resistances, regardless of the position of the switch. To check this switch it should be disconnected from the rest of the circuit first. Now there should be an open circuit between two of the contacts regardless of the position of the switch. There would be "throw" contacts, shown as H and L in figure 2. Between the third or common contact and either of the others there should be an open circuit in one position of the switch and a short in the other. If the switch is bad and needs replacing, make sure that the common wire is connected to the common contact of the new switch.

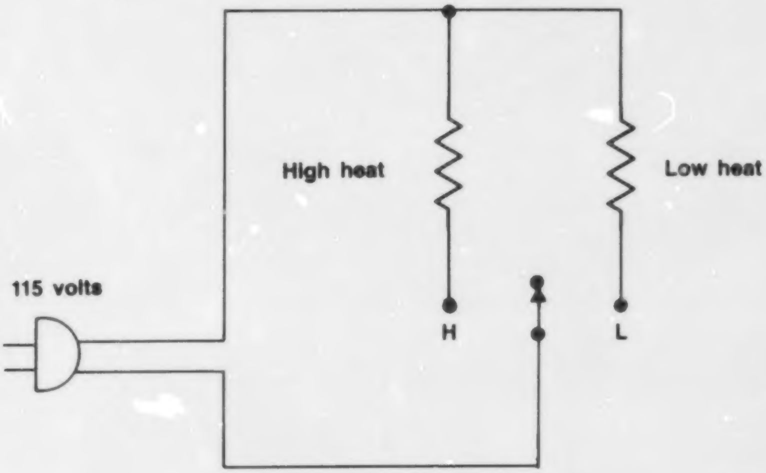


Fig. 2. Single-pole, double-throw switch

A double-pole, double-throw switch is shown in figure 3. When the switch is closed to the right, wire A is connected to wire C, and wire B to wire D. When the switch is moved to the left, A is connected to E, and B to F. In effect, the two switches are physically tied together so that both are thrown simultaneously by moving only one lever. A switch similar to this is used to operate a series motor and to reverse the direction of the windings in the motor. For instance, in an electric drill that reverses direction, the switch is thrown to one pair of connections or the other. In other applications, there may be a neutral or off position between the two, but the switch is still double-throw.

A common application of a single-pole, double-throw switch is to control a ceiling light fixture from two switches at either end of a room. Two such switches are used, as shown in figure 4. When both switches are connected to the same wire running between them, the circuit is closed, and the light is on. If either switch is thrown to the other wire, there is no continuous circuit, and the light goes off.

An unusual application of switching is in an electric range. Using two identical Calrod elements in one heating unit, with appropriate switches, it is possible to get five different degrees of heat. In figure 5, two 80-ohm elements are shown. The range is serviced by a three-wire line, where one line is at ground and each of the other two is 120 volts from ground. The phases of the two hot lines are such that they differ by 240 volts.

In figure 5A, both 80-ohm elements are in parallel across 240 volts. Each draws 3 amp, and the total power in both is 1,440 watts. In figure 5B, the 240-volt line is across one 80-ohm element to produce 720 watts. In figure 5C, each of the elements is across 120 volts and draws 1.5 amp. The total current of 3 amp produces 360 watts.

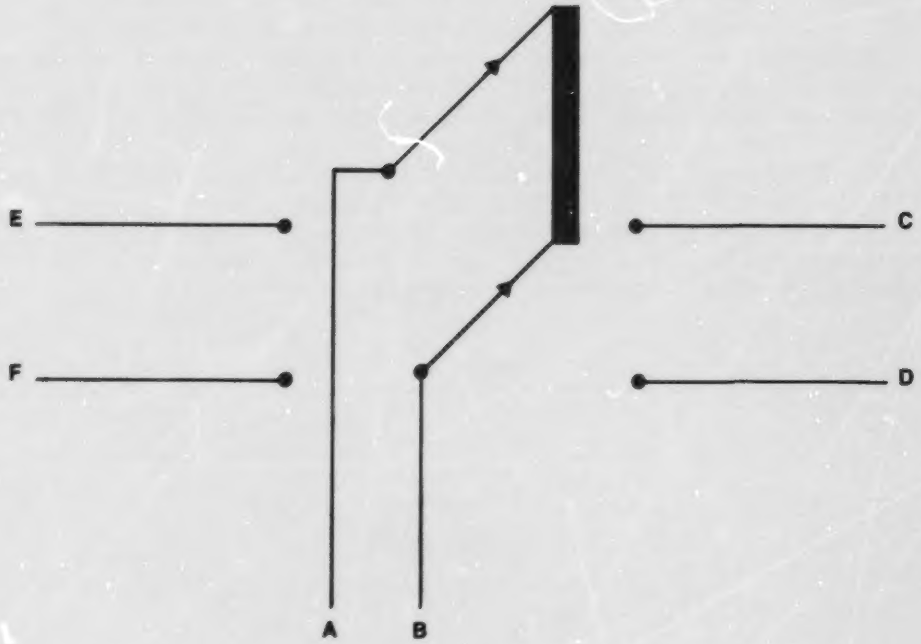


Fig. 3. Double-pole, double-throw switch

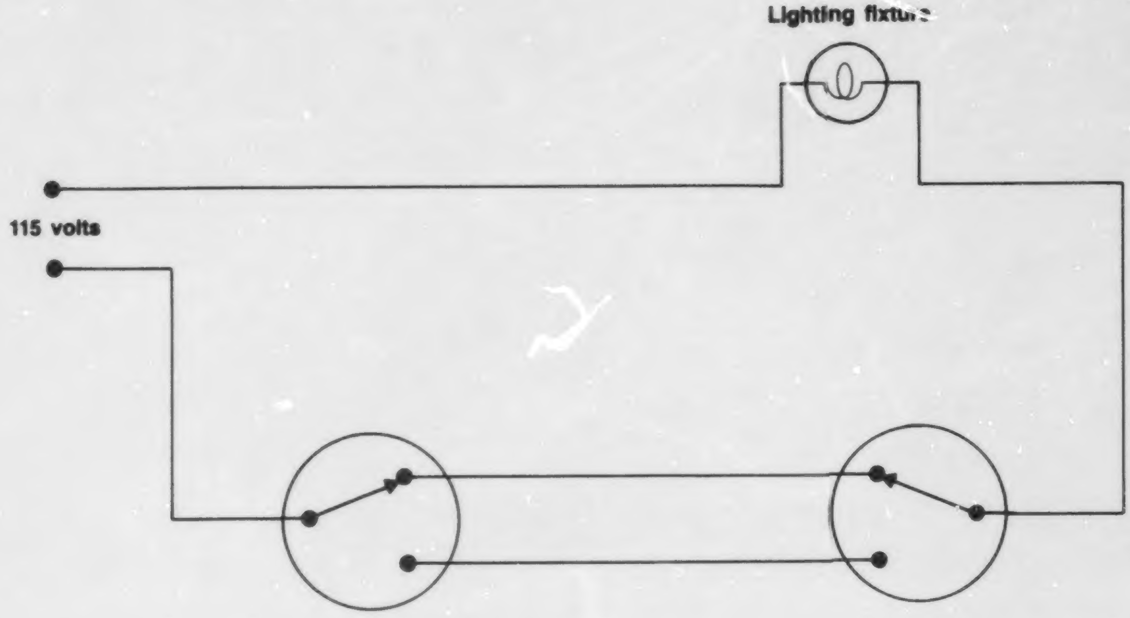

Lighting fixture
115 volts

Fig. 4. Two switches for room lighting

In figure 5D, only one element is used across 120 volts, producing 180 watts. Finally, in figure 5E, both elements are in series across the 120-volt line. The 160-ohm resistance draws 0.75 amp, and the power is only 90 watts.

A very common appliance, found in most homes today, is a three-way lamp. In most of these lamps, two or more bulbs are switched on separately or in combination. In another type, a single three-way bulb is used which has two filaments. These filaments can be switched on separately or together. Two of the most popular types of the three-way bulbs are the 100-200-300 watt and the 50-200-250 watt bulbs. In both the multiple bulb version and the three-way bulb, the degree of lighting is controlled by a switch. This is usually a rotary switch with a camlike blade (see fig. 6). The three-way bulb itself has two filaments. In the 100-200-300 watt bulb, the low filament draws 100 watts, and the high filament draws 200 watts. In the 50-200-250 watt bulb, the low and high filaments draw 50 and 200 watts, respectively. In figure 6 the two contacts are numbered 1 and 2. With the switch blade as shown, neither filament is connected, and the lamp is off. As the switch is rotated, detents stop it at the proper contact positions. In the first position, the narrow part of the blade contacts point 1 and closes the circuit to the low

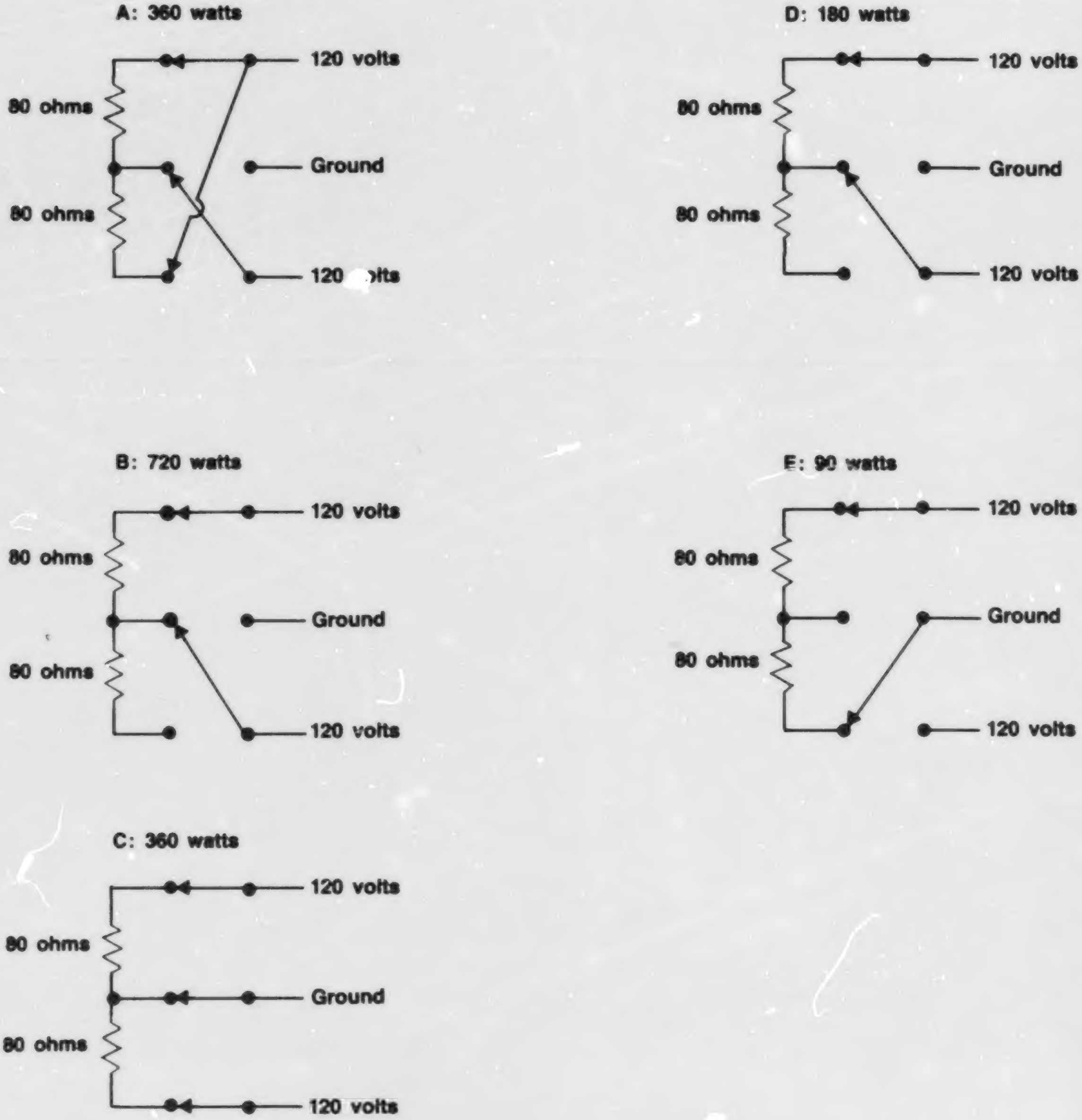

A: 360 watts
80 ohms
80 ohms
120 volts
Ground
120 volts
D: 180 watts
80 ohms
80 ohms
120 volts
Ground
120 volts
B: 720 watts
80 ohms
80 ohms
120 volts
Ground
120 volts
E: 90 watts
80 ohms
80 ohms
120 volts
Ground
120 volts
C: 360 watts
80 ohms
80 ohms
120 volts
Ground
120 volts

Fig. 5. Electric range connections

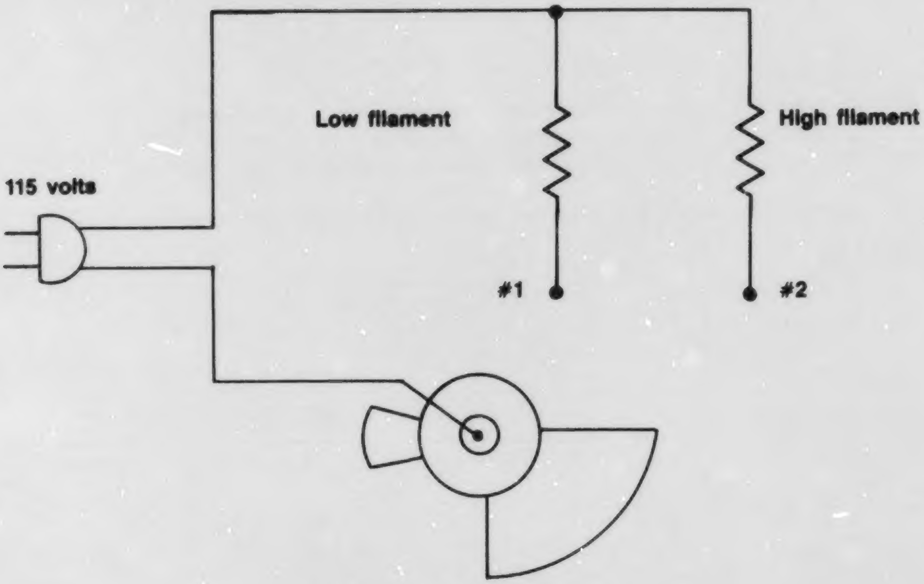


Fig. 6. Three-way lamp switch

filament. In the second position, the narrow blade touches point 2, and the opening between the blades falls in the vicinity of point 1. Therefore, only the high filament is connected. In the third position, the wide blade touches both points 1 and 2, and both filaments light. Then the switch is moved to the next position, which is the off position shown. In the lamp with separate bulbs, the switch operates in the same manner.

A three-way lamp can develop trouble in the switch itself or in the contacts to the bulb. A noisy switch indicates arcing inside and is usually a sign that the switch will soon fail. As with most switches, it doesn't pay to try to repair it. Simply replace the switch with a new one that has the same rating. In some lamps the switch can be separated from the socket. In others the two are integral. Before buying a new switch, open the housing, and see just what it is you will need.

To take apart the switch housing, look for small screws that hold it together. Some housings are held together by friction and can be pulled apart. Notice in figure 6 that one wire from the power line goes directly to the bulb filaments and does not go through the switch. However, in the lamp, you will find all the wires in a bunch, and you must separate them to determine which is the common wire. You usually will leave the common wire undisturbed and remove only the wires actually connected to the switch. You must note how they are screwed on the switch terminals and replace them the same way on the new switch.

Exercise

1. What is the primary function of switches?
2. Explain how a single-pole, single-throw switch is connected in a light circuit.
3. How does a single-pole, double-throw switch work?
4. Describe how to use an ohmmeter to troubleshoot a switch.
5. What type of switch is used in a three-way lamp?
6. Why is it easier to replace a switch then to repair it?

F-2

Timers and Solenoids

Objectives: After completing this assignment, you will be able to—

1. describe the operation of a timer;
2. explain how to clean the contacts of a timer;
3. describe the operation of a solenoid; and
4. explain how to troubleshoot a solenoid.

Timers

Large automatic electrical appliances must be controlled so that each function is performed in the exact sequence. In a dishwasher, the first operation is performed by the pump. The pump sucks out any water left over from the last time the dishwasher was used. After the pump stops, the timer then sends a signal to the hot water line to open, allowing hot water to enter the dishwasher. When the water has reached the desired level, the valve closes, and the motor starts and allows the water and soap to mix and spray over the dishes. After a period of time, the motor stops, and the pump starts and empties the soapy water. The timer then allows clean water to enter the machine to complete a second wash cycle or a rinse cycle, whichever is chosen. Finally, a heating element is activated to dry the load. Each of these functions is turned off and on by an electrical device called a *master control* or *timer.*

The heart of the timer is simply an electric clock motor that runs at a constant speed. A set of gears reduces the speed so that the motor rotates a spindle at the rate of one revolution for one complete operation of the appliance. This is just like a gear train in an electric clock that steps down the motor speed so that the minute hand makes one revolution per hour. The exact gear ratio varies with the make of the appliance. If the complete wash-rinse-dry cycle is supposed to take 45 minutes, the gear ratio will allow the spindle to make one revolution in 45 minutes.

Mounted on the spindle and firmly attached to it are several cams (see fig. 1). These cams have projections on them to actuate switches, and each cam controls a separate function of the appliance. One cam turns the motor on and off, another controls the valve for water level, and another controls the heating element. Figure 2 shows a simple cam and the switch it controls. A spring rides on the edge of the cam. When it is raised by a projection, it closes a pair of contacts (fig. 2A). In figure 2B, the spring is between projections, and the contacts are open. The number of projections on each cam and the length of each projection represent the number of times the switch must be closed and opened and the length of time it remains closed.

If the cam turned at a constant speed, the switches would open and close slowly. The current flowing at the moment of opening would cause sparking. This would pit the contacts, possibly welding them shut or not making a good contact. To prevent this from happening, the spindle is spring-loaded in such a manner that it moves in short impulses instead of turning smoothly. Each impulse is rapid, but with pauses in between, so that the total time of rotation is still held to one complete cycle of the appliance.

This type of timer (cams and switches) is the most common type in use today, but there are others. The newest type on the market is the all-

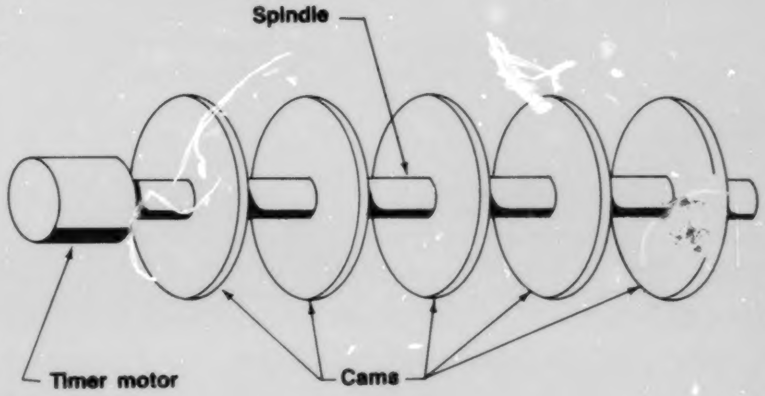


Fig. 1. Cam assembly

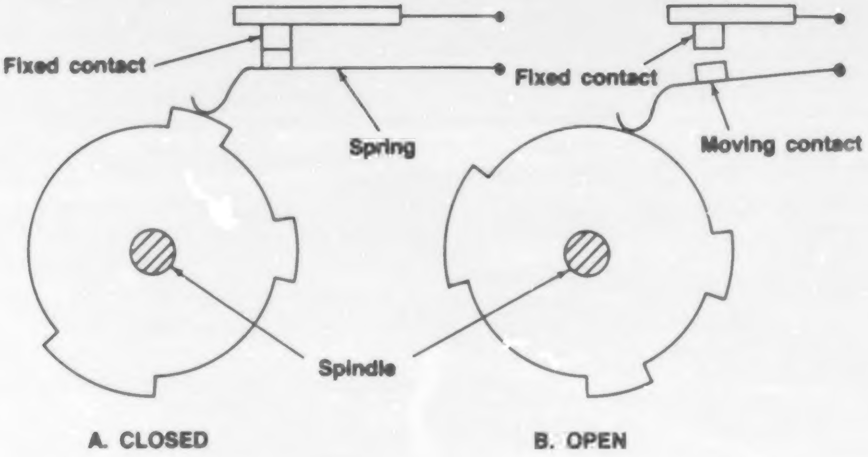


Fig. 2. Cam and switch

electronic timer. It is difficult and costly to repair, so it is usually replaced. The common timer motor rarely needs servicing, but if it fails, it should be replaced by an identical part. Before removing the old timer motor, however, make sure that it is receiving the proper voltage at its terminals. If there is voltage, but the timer motor does not run, see if there are mechanical restrictions, such as stuck bearings in the gear box, before deciding the motor is bad and needs to be replaced.

The most common fault in the timer is a pair of switch contacts that are welded shut from arcing. The switch lever should move easily when pushed with the fingers and should spring open when released. If contacts are stuck together, pry them apart, being careful not to bend the springs, and clean them with sandpaper. Contacts may also be pitted and burned so badly that they fail to make an electrical connection. Again, they should be sandpapered smooth. Never use emery paper, since the grit is conductive and can cause a short circuit if particles fall in the wrong places.

If a cam becomes loose on the motor spindle, you can tighten it, but you must first find out where in the cycle the particular switch opens and closes. Some manufacturers supply this information in the instruction sheets in the form of a timetable for the different functions. You can also get this information from an authorized service dealer. If the cam is twisted on the spindle, the switch will open and close at the improper time in the cycle.

Solenoids

A solenoid is an electromagnet. Basically, it consists of a coil of wire and an iron bar that is free to move through the coil. A spring holds the bar outside the coil when the circuit is disconnected (see fig. 3). When the coil is energized (when voltage is applied), current flows and makes the coil into a magnet. The iron bar is pulled into the center of the coil. When the voltage is disconnected, the spring pulls the bar out again. The bar can be attached to a mechanical linkage to shift gears, tighten a belt drive, open or close a valve, start or stop an agitator in a washer, or perform almost any mechanical function.

The most common example used in appliances is the water valve (fig. 4). When the coil is energized, the pointed iron rod is pulled up, and water flows through the pipe to the tub. When the electricity is turned off, the bar is pushed down and blocks the pipe, stopping the flow of water. The coil itself is usually a separate entity that is slid over the outside of the valve and is easily removed for testing and replacing.

A *relay* is a solenoid that controls a

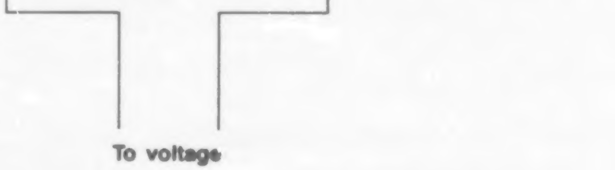


Fig. 3. Solenoid

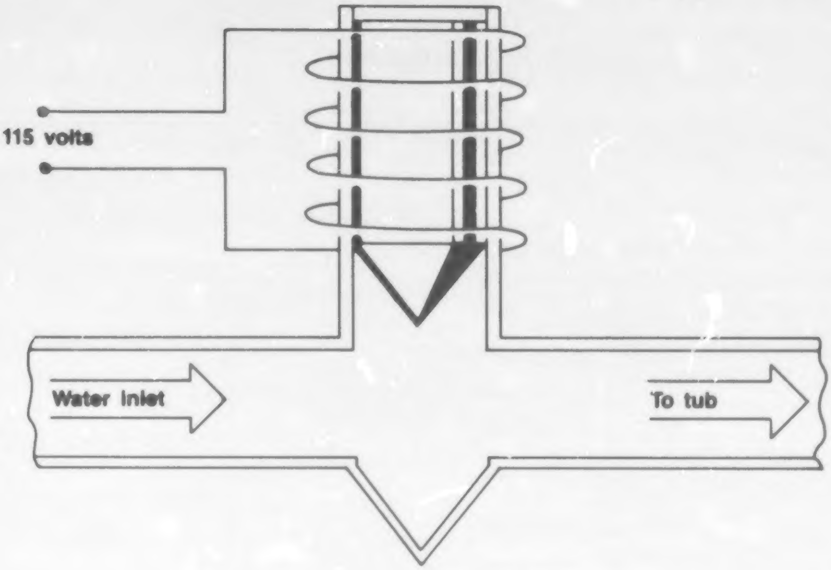


Fig. 4. Water valve

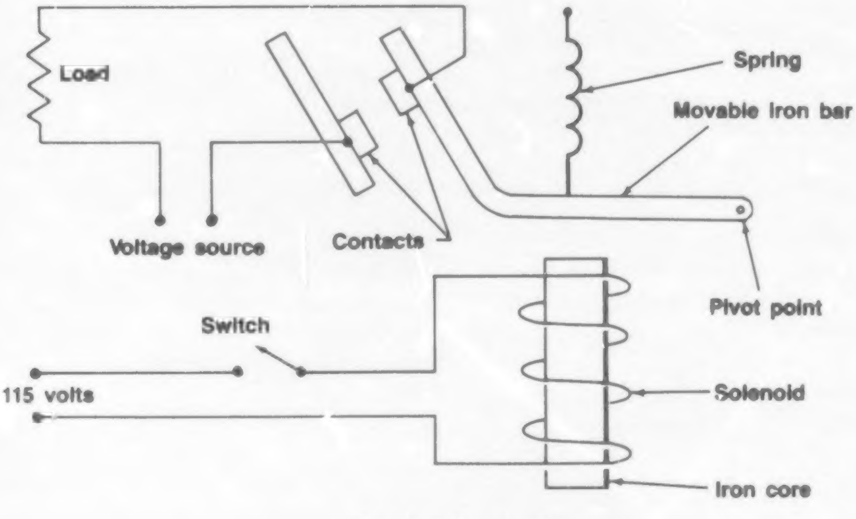


Fig. 5. Relay circuit

high current or voltage. For example, some of the functions in a dishwasher, such as drying, draw currents that are too great for the small contacts in the timer. The small contacts close a circuit to energize a solenoid, and the solenoid closes a pair of heavier contacts to start a larger current. A typical relay circuit is shown in Figure 5. The solenoid coil is wound permanently on an iron core to make a strong electromagnet.

When the switch is closed, current flows through the coil, making it a magnet. It attracts the movable soft iron bar holding one heavy contact. Since one end of this bar is fixed on a pivot point, the bar rotates on this pivot. In doing so, the heavy contact on the bar is brought against a fixed contact, closing the electric circuit to the load. The voltage source can be a heavy-duty, 240-volt line or a battery or whatever is required. When the switch is opened, the solenoid no longer attracts the movable arm, and the spring pulls the arm away, separating the contacts.

The most common trouble in a solenoid or relay is an open coil or a grounded coil. If a solenoid fails to operate, make a continuity test at its terminals. You should read a small resistance on an ohmmeter, which is the resistance of the coil. If you use a test lamp, the light should glow, indicating continuity. Also, check continuity between each of the solenoid terminals and the case. Here you would have no continuity unless the coil is grounded. If the coil is open or grounded, it can usually be replaced easily. In some small relays, it may be cheaper to replace the whole relay.

Check relay contacts for continuity when they are closed. If necessary, sandpaper them smooth. Many troubles with relays and solenoids are mechanical. The pivot points in the relay may need a drop of oil. Valves which are operated by solenoids may be stuck. In general, if the solenoid coil is all right, the trouble is not in the solenoid but is probably a mechanical problem in the part operated by the solenoid.

Exercise

1. What is the heart of a timer?
2. What is the most common fault in the timer?
3. When contacts are stuck together, what can you do?
4. Name the parts of a solenoid.
5. What functions can a solenoid perform?
6. What is a relay?
7. What is the most common trouble in a solenoid?
8. How do you check a solenoid that is not working?

Section

G

Electromagnetic Fundamentals of AC Generators, Transformers, and Motors

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G-1. The Generation of Alternating Current
G-2. Transformers
G-3. Theory of Electric Motors

Objectives: After completing this assignment, you will be able to—

1. state three factors that determine the magnitude (strength) of an induced electromotive force (emf);
2. define *alternating current;*
3. define the *frequency* of an alternating current;
4. define *phase difference;* and
5. explain how a revolving or rotating magnetic field is set up in an alternator.

G-1

The Generation of Alternating Current

Electromagnetic Induction from Cutting of Magnetic Field by a Conductor

As a source of commercial electrical energy on a large-scale basis, batteries are relatively expensive and unwieldy. Therefore, other means are used to obtain electrical energy in large quantities. Probably the most common source of electrical energy is the *generator,* which depends on the principle of electromagnetic induction for its operation. This principle was discovered by Michael Faraday in 1831 and can be demonstrated easily as follows:

1. Connect a highly sensitive current-indicating device, such as a zero-center galvanometer (fig. 1), to the ends of a conductor, such as copper wire, and move the conductor downward through a magnetic field so that the conductor cuts across the magnetic flux.

2. When this is done, a momentary voltage will be induced in the conductor with polarity as indicated. This induced voltage, in turn, will cause current (electrons) to flow through the galvanometer and move its indicating needle. This momentary deflection of the galvanometer needle is an indication that a voltage has been induced in the conductor. The current caused by the induced voltage is called the induced current.

3. If the conductor is held stationary in the magnetic field, the galvanometer needle will indicate zero, thus showing that no voltage is being induced in the conductor.

4. If the conductor is moved upward through the magnetic field, the galvanometer needle will again be deflected, although in the opposite direction to that when the conductor was moved downward. This indicates that the polarity of the induced voltage has been reversed, thus reversing the direction of the induced current through the galvanometer.

5. If the conductor is moved in the field sideways, from the north pole to the south pole of the magnet or vice versa, so that no lines of force are cut, the galvanometer needle will remain at zero, indicating that no voltage is being induced in the conductor. As the angle between the flux lines and the path of the conductor is increased, the deflection of the galvanometer in-

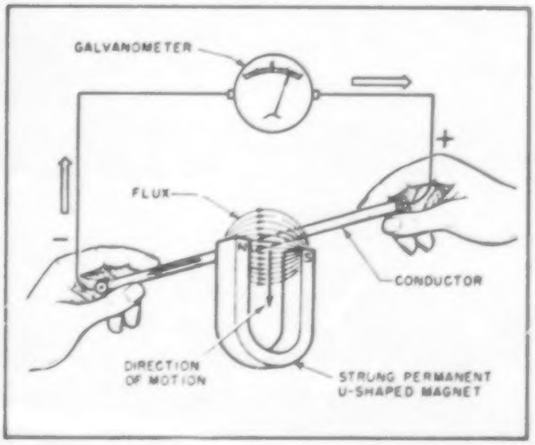


Fig. 1. Induced current

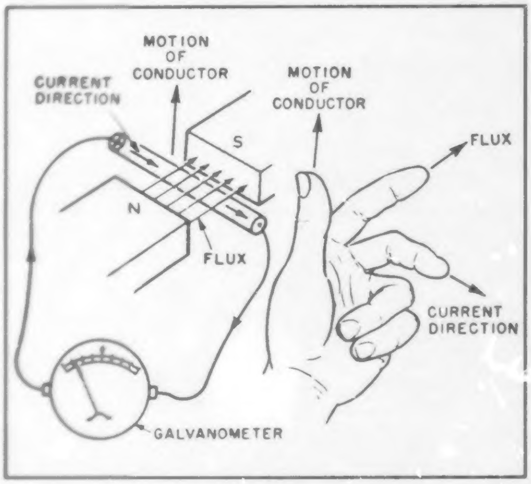


Fig. 2. Left-hand generator rule

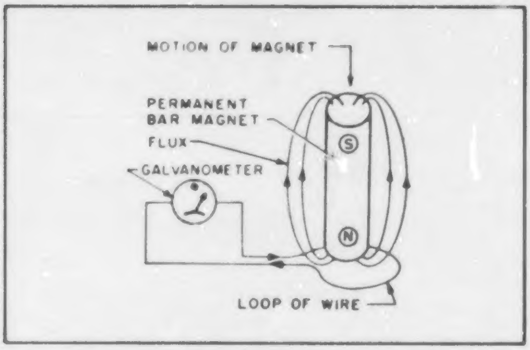


Fig. 3. Inducing an emf in a loop

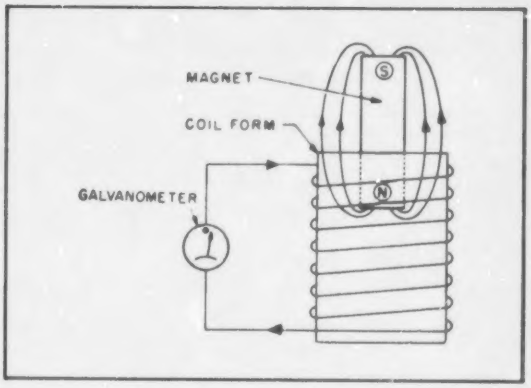


Fig. 4. Inducing an emf in a coil

creases until the maximum deflection is obtained when the conductor is swept through the magnetic field at right angles (90 degrees) to it.

If the polarity of the magnetic field is changed—that is, if the north and south poles of the magnet are interchanged—the polarity of the induced voltage will be reversed also.

The above experiment shows that the conductor must cut through the magnetic field in order to have a voltage induced in it and, also, that the polarity of the induced voltage depends on the direction of motion of the conductor and the direction of the magnetic field.

Left-Hand Generator Rule

The relationship between the motion of the conductor, the magnetic flux it cuts, and the direction of the induced current is summed up by the left-hand generator rule (fig. 2). With the thumb, forefinger, and middle finger of the left hand set perpendicularly to each other as shown, point the forefinger in the direction of the flux, and point the thumb in the direction of motion of the conductor. The middle finger will then point in the direction in which the generated or induced voltage tends to send the current through the circuit.

Electromagnetic Induction from Cutting of Conductor by Magnetic Field

You have seen that a voltage is induced in a conductor when it is moved through a magnetic field. The reverse of this is also true. That is, if the conductor in figure 2 is held stationary, and the magnet is moved so that its field cuts the conductor, a voltage will be induced in the conductor. In other words, it makes no difference if the magnetic field is kept stationary and the conductor cuts it in a downward direction, or if the conductor is held stationary and the magnetic field cuts it in an upward direction. The induced voltage and current will be exactly the same and have the same polarity. This is to be expected since the relative motion of the magnetic field with respect to the conductor is the same in either case. To apply the left-hand generator rule, however, it is always necessary to assume that the magnetic field is stationary and that the conductor is cutting it.

Another example of inducing a voltage by cutting a conductor with a moving magnetic field is illustrated in figure 3. In this case, the conductor is a loop of wire, the ends of which are connected to a galvanometer. When a permanent bar magnet is thrust through the stationary loop, the field of the magnet cuts the loop, as shown, and induces a voltage in it. The resulting current through the galvanometer causes a deflection of the needle. If the magnet is held stationary in the stationary loop, no voltage is induced. If the magnet is withdrawn from the loop, a voltage of opposite polarity will be induced in the loop.

The principle of electromagnetic induction can then be stated as follows: Whenever there is relative motion between a conductor and a magnetic field, a voltage will be induced in the conductor. The motion may be produced either by moving the conductor through a stationary magnetic field or by making the magnetic field move through and cut a stationary conductor. The induced voltage is also referred to as the *induced emf.*

Factors Determining the Magnitude of the Induced Electromotive Force

Three factors determine the magnitude (strength) of the induced emf. The first factor is the number of turns in the conductor. In figure 3, only one loop of wire is used. If two loops of wire are used, the motion of the magnet through the loops of wire will cause twice the deflection on the galvanometer that one turn will cause, everything else remaining equal. If more loops or turns of wire are added (fig. 4), the motion of the magnet will further increase the deflection of the galvanometer needle. It is apparent that *increasing the number of turns of wire increases the magnitude of the induced emf.* The reason for this is that the turns of wire are actually connected in series and the induced voltage is the sum of the voltages induced in the individual turns.

The second factor in increasing the induced emf is to increase the strength of the magnetic field. This can be done by utilizing a winding around the magnet and making it an electromagnet with a greatly increased field strength (fig. 5). The cutting of this field by a conductor will produce a greatly increased emf. *Increasing the* *field strength increases the induced emf.*

The third factor that determines the magnitude of the induced emf is the speed of the conductor and the magnetic field. If the conductor is passed through the magnetic field, first slowly and then rapidly, a much greater emf is induced when the conductor is moved rapidly. *Increasing the speed of the conductor (of magnetic field) increases the induced emf.*

Summing up, whenever there is a relative motion between a conductor and a magnetic field, the magnitude of the emf induced in the conductor is directly proportional to (1) the number of turns in the conductor, (2) the strength of the magnetic field, and (3) the speed of the relative motion between the conductor and the magnetic field.

How Electricity Is Generated

Figure 6 is a simplified diagram of a generator. A magnetic field is established between north and south poles by means of an "exciting" current flowing in winding W. A loop of wire I in this field is arranged so that it can be rotated on the axis X, and the ends of this loop are brought to slip rings SS on which brushes BB can slide. The circuit of which this rotating loop is a part is completed through the slip rings at A. When this loop is rotating, the conductors D and E have a voltage produced in them that will cause a current to flow out to A where the circuit is completed.

Figure 7 shows a series of diagrams still more simplified in which the magnetic field is merely indicated. The loop of wire is assumed to be rotating with a uniform speed in the direction shown by the curved arrows. At "start," the voltage will be zero because the conductor is moving parallel to the magnetic field. Gradually, as it revolves, it begins to cut more and more across the field, until a quarter of a revolution later, at "¼ cycle," it is cutting squarely across the field. At this point, the voltage in the conductor will be a maximum but will reduce again as the loop revolves to "½ cycle," where it is zero. Then the

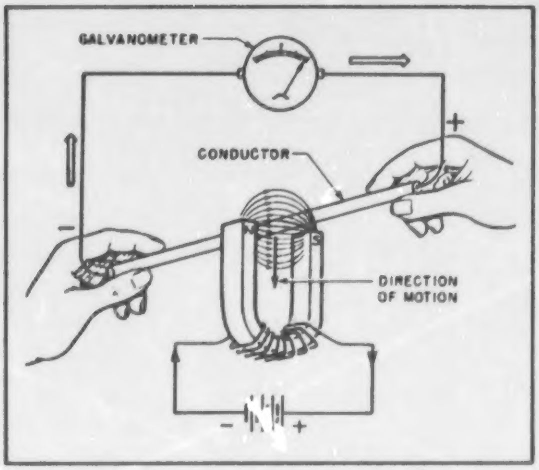


Fig. 5. *Increasing the field strength increases the induced emf.*

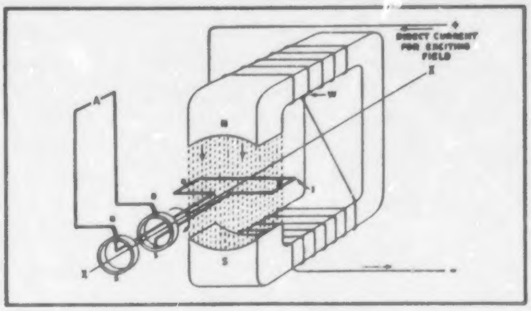


Fig. 6. *Single-phase, revolving-armature alternator*

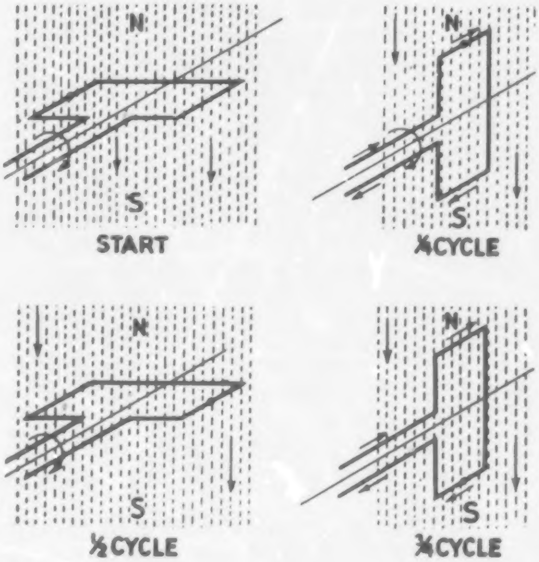


Fig. 7. *Loop of wire rotating in a magnetic field*

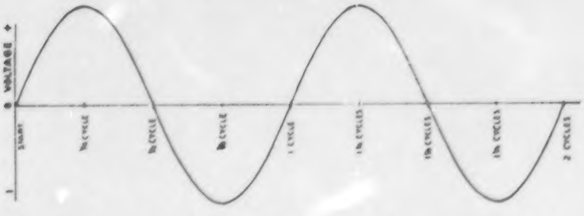


Fig. 8. Variations in voltage (single-phase voltage curve)

voltage will rise in the opposite direction until a maximum is reached at "¾ cycle" and finally return to the original position where the voltage is zero. Thus, as the conductor passes under a pair of north and south poles, a cycle of voltages takes place, being first in one direction and then in the other. The unmarked conductor forming the opposite side of the loop always has a voltage produced in it as it passes under the pole of opposite polarity. The voltages in these two conductors always add together, and the voltage across the entire loop is equal to their sum.

Figure 8 shows these changes in voltage graphically. The curved line represents the voltage at any instant by its vertical distance above or below the horizontal axis line. At the start, the voltage is zero, when both conductors are moving parallel to the field. Then the voltage rises to a positive maximum as the conductors pass under the poles at "¼ cycle." Then it falls to zero, reverses, goes to a negative maximum as the conductors pass under the opposite poles, and finally returns to zero as the loop completes the cycle and starts on another one. The current in this circuit rises and fails with the voltage. It flows alternately first one way and then the other—hence the name *alternating current*.

Alternating current is defined as a current that is constantly changing in magnitude and periodically changing direction. The generator shown in figures 6 and 7 is a two-pole, single-phase, revolving-armature, alternating-current generator. The magnetic field, the coils of wire, and the iron core are called the *field* of the generator. The rotating loop in which the voltage is produced is called the *armature*.

Alternating Current and Voltage Values

If the voltage completes 60 cycles in one second, it is called a *60-cycle* voltage. The current that this voltage will cause to flow will be a 60-cycle current.

Maximum voltage or current is the highest value reached in a cycle (fig. 9). The **maximum value** of current or voltage is 1.414 times the effective value. The maximum voltage is important when considering insulation for a circuit.

The **average value** of an alternating current or alternating voltage is the average of all the instantaneous values for one-half cycle. The positive half of an alternating-current sine wave or voltage is usually of the same form and value as the negative half of the wave, so that it is necessary to consider only one-half of the cycle. The accuracy of the calculation for the average value of current or emf depends on the number of instantaneous values used. The more values used, the closer the answer is to the true average value. Average values are little used except in calculations and in work with rectified current. An exact calculation of average values requires the use of higher mathematics. The average voltage (E_{av}) and average current (I_{av}) are 0.636 times the maximum value (see fig. 9).

The **effective values** of current and voltage in an alternating circuit are measured in terms of the units of direct current. The effective value of an alternating current is that value which produces the same heating effect as a direct current of the same amount. In other words, 10 amp of alternating current produce the same heating effect as 10 amp of direct current. Since the heating effect is not affected by the direction of flow, an alternating current will heat an incandescent lamp bulb to the same brightness as a direct current of the same value.

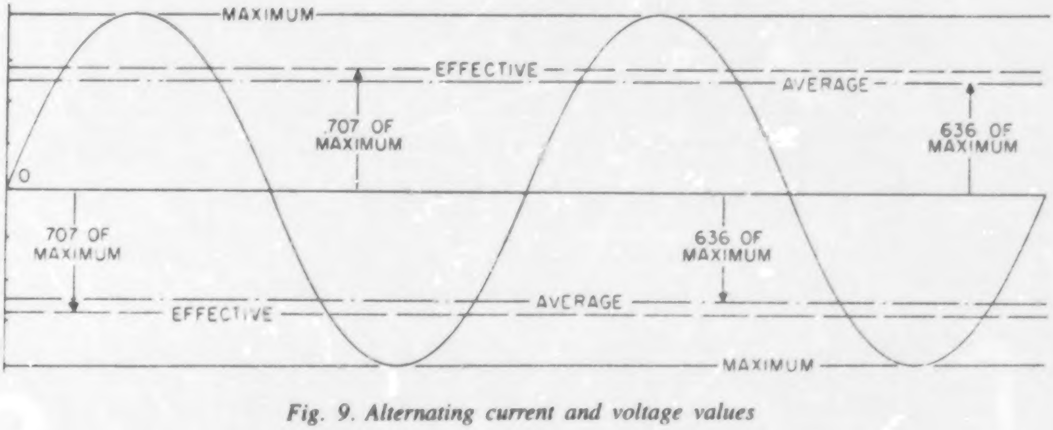


Fig. 9. Alternating current and voltage values

The effective value of current is sometimes referred to as *root-mean-square (rms) value*, because it is the square root of the average of the squared instantaneous values. The effective numerical value of an alternating current or voltage is 0.707 times the maximum value (fig. 9). For practical purposes, effective (or rms) values are more important than instantaneous, average, or maximum values because AC voltmeters, ammeters, and wattmeters are calibrated to read effective values. When values of alternating current (I) or voltage (E) are used, effective values are meant unless otherwise stated.

Two-Phase Generator or Alternator

A two-phase generator is really a combination of two single-phase generators. Figure 10 (top) is a diagram of two single-phase generators, or *alternators*, which is the term applied to an alternating-current generator. The armatures of these machines are mounted on one long shaft and must revolve together, always at right angles to each other.

Then, when phase 1 is in such a position that the voltage in it is at a maximum, phase 2 is in such a position that voltage in it is zero. A quarter of a cycle later, phase 1 will be zero, and phase 2 will have advanced to the position previously occupied by phase 1, and its voltage will be at a maximum. Thus, phase 2 follows phase 1, and the voltage is always just a quarter of a cycle behind because of the relative mechanical position of the armatures. Figure 10 (bottom) is a diagram of the relation of these voltages. It will be seen that phase 2 repeats all the alternations of phase 1 a quarter of a cycle later.

Figure 11 shows how these two alternators are put together and rotate through the same magnetic field on the same shaft. This makes a two-phase alternator, and each external circuit is separate just as though there were two alternators.

Three-Phase Alternator

In a three-phase alternator, three single-phase windings are combined on a single shaft and rotate in the same magnetic field (see fig. 12). Each end of each winding can be brought out to a slip ring and an external circuit. In the three-phase alternator, the voltage in each phase alternates exactly a third of a cycle after the one ahead of it because of the mechanical arrangement of the machine. When the voltage in phase 1 is approaching a positive maximum, as shown at "start" in figure 13, the voltage in phase 2 is at a negative maximum and the voltage in phase 3 is falling. The succeeding variations of these voltages are also shown in figure 13.

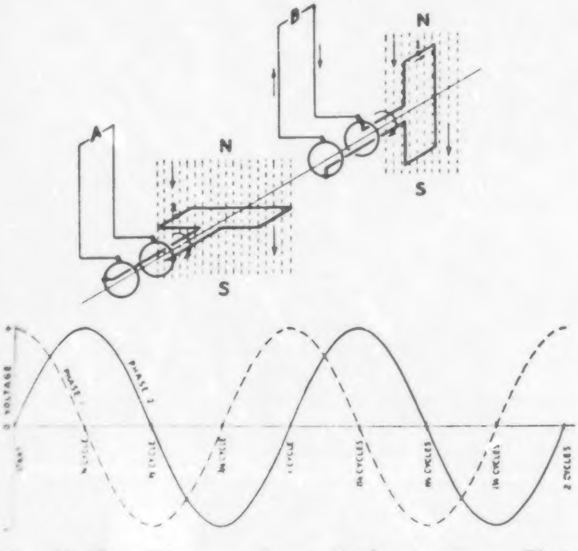


Fig. 10. ***Top****: Diagram of two simple generators. Their single-loop armatures rotate on the same shaft always at right angles to each other and in fields of the same strength.* ***Bottom****: Curves representing the voltages in two separate loops of wire rotating together always at right angles to each other. This is a two-phase voltage curve.*

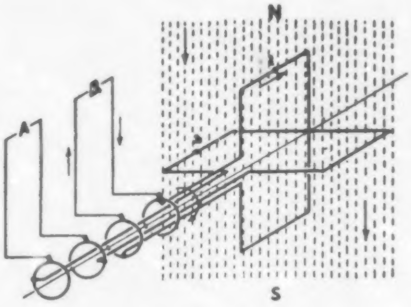


Fig. 11. When the two single-phase alternators are combined into one machine, with both armature windings rotating in one magnetic field, a two-phase alternator is the result.

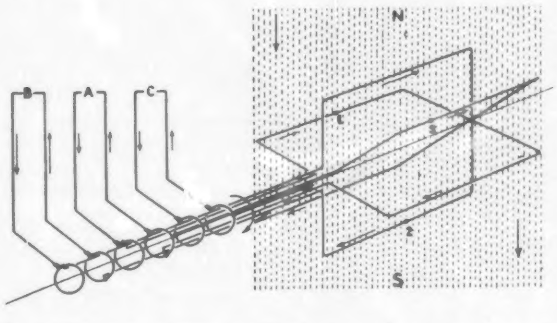


Fig. 12. Three separate loops of wire—three simple armatures—are revolving in the same magnetic field, with each loop brought out to a separate pair of slip rings and a separate external circuit.

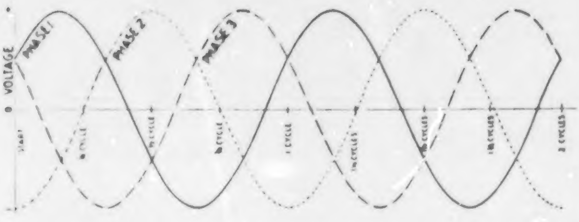


Fig. 13. Voltage variations of a three-phase alternator

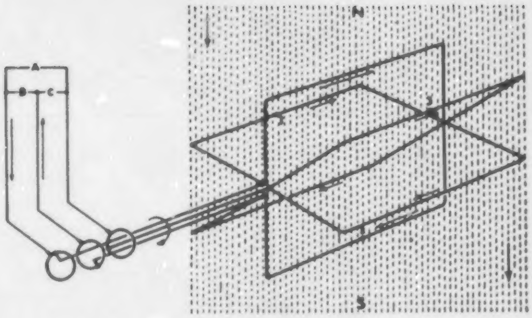


Fig. 14. If these three loops are connected together within the machine, only three slip rings are needed because each ring can serve two outside circuits.

As a rule, each end of each phase winding is not brought out to a separate slip ring in a three-phase machine, but the three phases are all connected together, as shown in figure 14, for instance. This makes only three leads necessary for a three-phase winding, with each lead serving two phases. Then each pair of wires acts like a single-phase circuit, largely independent of the other phases. Power is generally produced and transmitted in three-phase systems, because this is best adapted to motors and involves the least expensive power lines.

Are more than three phases ever used? Machines could be built for almost any number of phases, but this is more expensive and there is little advantage in using more than three phases. Thus, it is very seldom done, except for certain converting machines that often use six phases.

Multipolar Machine

A multipolar motor or generator is one that has more than a single pair of north and south poles. Most electric motors and generators have four poles or more. The number of poles is always even because for every north pole there is a corresponding south pole.

Figure 15 shows a four-pole, single-phase, revolving-armature alternator. In this diagram, any conductor passes first under a north and then under a south pole, but in one revolution of the shaft this conductor has passed by four poles—that is, two pairs of poles—giving two complete cycles for one revolution. If the machine had six poles, each revolution would have three cycles, one for each pair of poles. If an alternator has two pairs of poles and runs at 1,800 revolutions per minute (rpm), it will make two times 1,800 (or 3,600) cyles per minute. The *frequency* of a machine is always measured in cycles per second instead of per minute, so that you must divide the cycles per minute by 60 to get the frequency. In the example above, the frequency will be 3,600 divided by 60, or 60 cycles per second. The general formula relating to frequency, speed, and number of poles is

$f = \text{rpm} \times p/120$

Where: f = frequency, in cycles per second
rpm = speed, in revolutions per minute
p = number of poles

By far the most common frequency is 60 cycles per second, but frequencies of 25, 40, 50, and even others are used in some places.

An alternator designed to be driven by a steam engine, oil engine, large water turbine, or other slowly revolv-

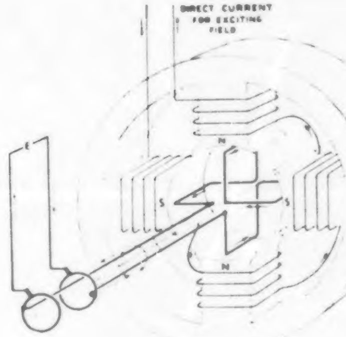


Fig. 15. A simple alternator with a revolving armature and four poles. This is a single-phase machine. Remember that the number of poles a machine has does not determine the number of phases it has.

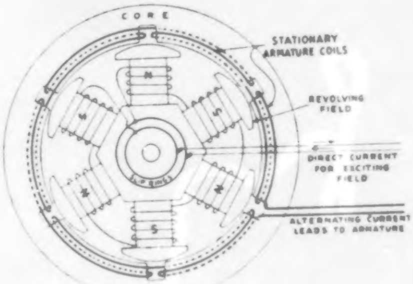

CORE
STATIONARY ARMATURE COILS
REVOLVING FIELD
DIRECT CURRENT FOR EXCITING FIELD
ALTERNATING CURRENT LEADS TO ARMATURE
N
S
N
S
N
S

Fig. 16. A single-phase alternator with six poles in a revolving field

ing prime mover must run slowly if it is to be directly connected. Thus, it must have many poles, sometimes thirty or more. On the other hand, alternators that are to be directly connected to steam turbines often have only two or four poles because they must run at high speeds.

Direct-current motors and generators that do not have the limitations of frequency to determine the number of poles ordinarily have four. Small machines, however, may have two poles, and large ones often have six, eight, or even more.

Revolving-Field Machine

A revolving-field machine is a motor or generator in which the steady magnetic field revolves. In all of the diagrams presented thus far, the poles making up the magnetic field have been stationary on the frame of the machine, and the armature in which the voltages are produced has moved.

This arrangement is followed universally in direct-current machines, but alternating-current motors and generators usually have revolving fields, because it means that only two slip rings need to be used. These two carry the low-voltage exciting current to the field. For a three-phase machine, at least three slip rings would be required for the armature current that is often generated at a high voltage.

High-voltage windings that remain stationary can be insulated more effectively than when they must also resist the additional stresses of rotation. Of course, the result is the same whether the field or the armature revolves, since in either case the conductors cut across the magnetic field. Machines are built whichever way gives the best construction.

Figure 16 shows a diagram of a single-phase, revolving-field alternator. An alternator or generator converts mechanical power into electrical power.

Phase Difference

Phase is the difference in time between any point on a cycle and the beginning of that cycle. *Phase difference* is the difference in time between any two cycles—that is, between the time of the passing of one cycle through a given point and the time of the passing of the second cycle through the same point. Phase difference is usually expressed in electrical degrees.

If the phase difference between two cycles is zero, they are said to be *in phase*. If the phase difference is one quarter cycle, the two cycles are said to be *out of phase by 90 degrees*. The first cycle may be said to lead the second, or the second cycle may be said to lag the first, by 90 degrees. Two cycles that pass through their zero points and maximum points at the same time but in different directions are *180 degrees out of phase*. Phase difference is expressed in degrees from 0 to 180. An angle of lead, for instance, greater than 180 may be expressed as an angle of lag less than 180.

A two-phase voltage can be produced by placing two separate windings 90 mechanical degrees apart in a two-pole alternator. The two voltages have equal magnitudes, and they are out of phase by 90 electrical degrees.

A three-phase voltage can be produced by placing three separate windings 120 mechanical degrees apart in a two-pole alternator. The three voltages have equal magnitudes, and they are out of phase by 120 electrical degrees.

Exercise

1. What is the most common source of electrical energy?
2. What are three factors that determine the strength (magnitude) of an induced electromotive force (emf)?
3. Define *alternating current*.
4. How is a stationary magnetic field established in an AC generator or alternator?
5. What is a multipolar generator or alternator?
6. Define the *frequency* of an alternating current.
7. If an alternator generates 60 sine waves of voltage per second, what is the frequency of the voltage?
8. Explain why the effective values of alternating current and voltage are more important to the appliance repairer than the other values.
9. What is the phase of the voltage generated by an alternator that has three pairs of north and south magnetic poles?
10. Explain how a revolving or rotating magnetic field is set up in an alternator.
11. What is *phase difference?*

G-2

Transformers

Objectives: After completing this assignment, you will be able to—

1. tell why transformer cores are made of thin strips of metal with insulation material between them;
2. explain the connection between the coil windings of a transformer;
3. discuss the primary and secondary windings of a transformer;
4. discuss the power transfer through a transformer;
5. give the reason for using autotransformers in some AC motor circuits; and
6. define a *transformer.*

Advantages of Using Alternating Current

Alternating current is best suited for long-distance transmission because it may be easily generated at low to moderately high voltages and then have the voltage raised to very high values suitable for efficient transmission. Then the voltage can be once more quite readily reduced, by means of a stationary device known as a transformer, to a value suitable for general use. The higher the voltage or pressure, the smaller the wire required to carry a given amount of power—hence the advantage of high-voltage transmission.

For example, an alternator may generate power at 2,200 volts. Part of the current, by using transformers, may be supplied at 110 volts for lamps, part at 440 volts for motors, and part at 2,200 volts for high-voltage motors. Some may be stepped up to 110,000 volts for transmission to distant points where it is stepped down to any desired voltage before it is used. Such an arrangement is not possible with direct current since transformers cannot be used.

Definition of a Transformer

A *transformer* is a device by which the voltage of an alternating-current system may be changed. It consists of an iron core surrounded by coils of insulated copper wire. Usually, both the core and the coils are immersed in oil, which serves as an insulator and helps cool the transformer. The voltage is changed in exact proportion to the number of turns connected in series in each winding. For instance, if the high-voltage winding has 1,000 turns and is connected to a 2,200-volt circuit, a low-voltage winding of 100 turns will give 220 volts.

Transformers are usually wound for single-phase circuits and groups of three, used for three-phase transformation. However, three-phase transformers can be built and are often used. In either kind of transformer, the high-voltage and low-voltage windings are completely insulated from each other (see fig. 1).

An *autotransformer,* or *compensator,* has only one winding, part of it being for low voltage and all of it being connected in the high-voltage circuit, as shown in figure 2. In this transformer, the high-voltage circuit is not insulated from the low-voltage circuit.

Principle of Transformer Operation

The key word in transformer operation is *induction.* As has been pointed out, when the magnetic field that surrounds a conductor that carries a current moves across another conductor, a voltage is produced in the second conductor by induction. Note that *the magnetic field moves* but not the conductor itself.

When a wire is carrying alternating current, the magnetic field moves by reason of the pulsating or alternating nature of the current. Since alternating current (60-cycle current) rises from zero to a peak and back to zero 120 times per second, the magnetic lines of force surrounding the conductor move out and back 120 times per second also.

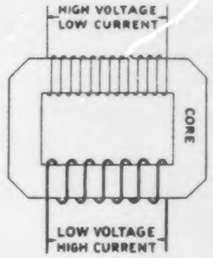


Fig. 1. A transformer with two windings insulated from each other

If another conductor is placed so that the magnetic lines of force move back and forth across it, a current will be induced in the second conductor. The following definitions and laws are important.

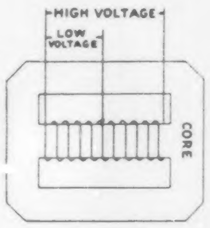


Fig. 2. An autotransformer has only one winding, which is divided into two parts. It also changes voltages but does not insulate the two circuits.

1. The conductor carrying the generated current is called the *primary*, and the conductor carrying induced current is called the *secondary*.
2. The two conductors are insulated from each other.
3. The induced current will have the same frequency as the primary current. The induced current, of course, will be alternating current.

Eddy Currents

The transformer shown in figure 3 consists of a primary winding and a secondary winding on a laminated core of thin sheets of silicon steel separated by insulators. A laminated core reduces the eddy currents that are present in solid iron type cores. Eddy currents heat the solid core and so waste energy.

It will be recalled that the current flowing in the primary coil induces magnetic lines of force in the core. These induced lines of force, in turn, induce currents that follow circular paths around the line of force. If the core is a solid piece of metal, these induced eddy currents will be present in a large segment of the metal. However, if the core is made up of thin strips of metal with insulating material between them, the eddy curents cannot cross through the insulation. This restriction confines the eddy currents to the thin strip and prevents, to a large extent, the heating of the core.

Figure 4A (a step-up transformer) and 4B (a step-down transformer) show the effect of the relative number of turns in the primary as compared with the secondary circuit. For example, if there are 1,000 turns in the secondary, and only 100 turns in the primary winding, the voltage induced in the secondary will be ten times greater than the voltage applied to the primary. Figure 4A shows that the primary winding has 110 volts and 100 turns, and, since there are 1,000 turns in the secondary winding, this gives a secondary voltage of 1,100 volts. This is called a *step-up transformer* since it steps up the voltage from 110 to 1,100. Any transformer that has more turns in the secondary coil than in the primary coil is a step-up transformer.

However, if the secondary has 10 turns and the primary has 100 turns, the voltage induced in the secondary will be one-tenth of the voltage applied to the primary. In figure 4B, the primary coil has 100 turns and is connected to a 110-volt AC supply. The secondary has only 10 turns and therefore has an induced voltage of 11 volts. When the secondary has fewer turns than the primary, the transformer is a *step-down transformer*. The ratio of the number of turns in the primary coil to the number of turns in the secondary coil—that is, the *turn ratio* of the transformer—determines the voltage output of the secondary in relation to the primary supply voltage.

Variable Emf Ratio

It is sometimes necessary to change the voltage ratio by changing the turn ratio in the transformer. This is done by placing taps on various turns on one or both of the windings. Then the voltage ratio is changed by connecting the transformer so that more turns or fewer turns are used in one of the windings (see fig. 5). Changing from one tap to another can be done by changing the line connection to the taps or by bringing the tap connections to a multiple contact switch. The sec-

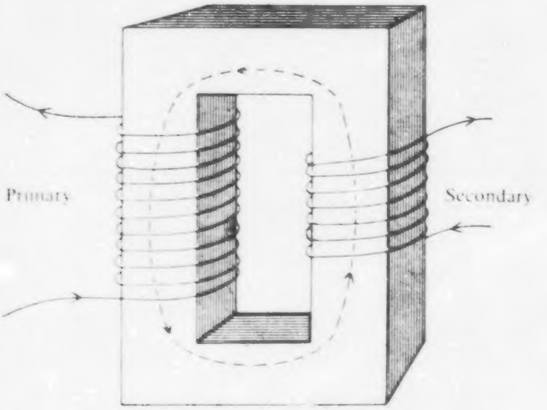


Fig. 3. A closed-core transformer with the windings in place

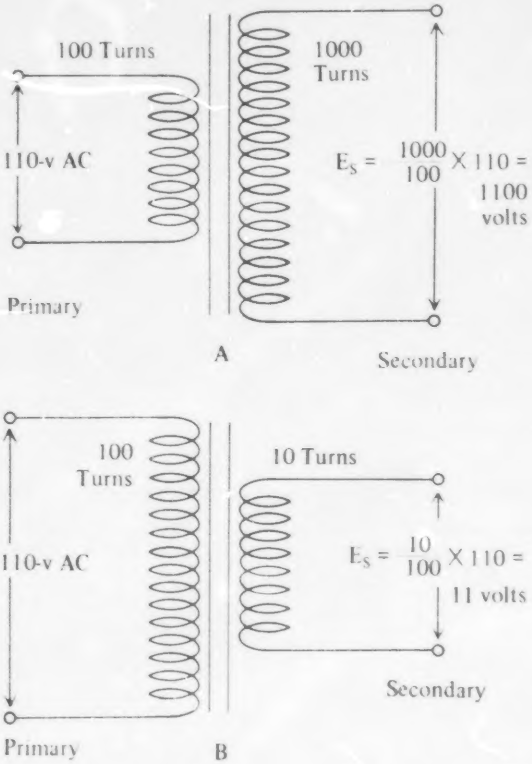

100 Turns
1000 Turns
110-v AC
$E_S = \frac{1000}{100} \times 110 =$ 1100 volts
Primary
A
Secondary
100 Turns
10 Turns
110-v AC
$E_S = \frac{10}{100} \times 110 =$ 11 volts
Secondary
Primary
B

Fig. 4. Ratio between voltage and the number of turns in the coil

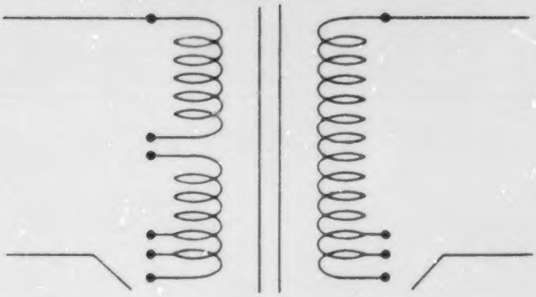


Fig. 5. Tapped coil

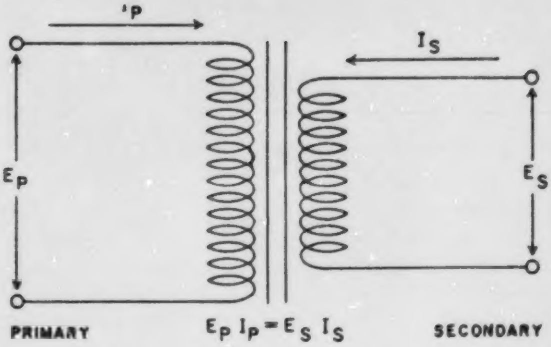


Fig. 6. Relationship of voltage and current in the primary and secondary

ondary winding may be in two or more sections so that voltage from one or more sections can be hooked in series or parallel as needed.

Current in Primary and Secondary

Current will flow in the secondary only when the secondary circuit is connected to a load. The current in the secondary of a transformer is stepped up or down in the reverse order to the ratio of the voltage. This means that in a step-up transformer the current in the secondary is lower than the current in the primary, by the inverse ratio of the voltage, primary to secondary.

Although transformer efficiency is not 100 percent, it may be considered so for practical purposes. Therefore, in a step-up transformer of one to five ratio, if the primary winding is 5 amp, then the current in the secondary is 1 amp. The voltage in the secondary is five times the primary voltage. Therefore, the current in the secondary is one-fifth as much as the primary current.

This means that the product of the current and voltage in the primary circuit of a transformer is equal to the product of the current and voltage in the secondary circuit. The step-down transformer in figure 6 shows this formula $E_p \times I_p = E_s \times I_s$ for the current and voltage relationship. The formula is true for both the step-up and step-down transformer if the small transformer loss is disregarded.

Counter Emf in the Primary

The ohmic resistance in a transformer winding is usually comparatively small in relation to voltage applied to the windings. The primary is connected directly across the line and would represent a short circuit if there were no other factors to limit primary current.

The voltage induced in the primary winding is 180 degrees out of phase with the incoming line voltage, or, in other words, directly opposed to it. This induced voltage in the primary is a *counter, or back, emf* that acts to limit the current that flows in the primary winding. The back emf is almost equal to the line voltage.

Since the magnetic flux that produces the induced voltage is set up by current from the primary source, there is always enough flux to induce a back emf equal to the line voltage less the loss due to resistance in the primary circuit and leakage or reactance losses. The voltage impressed on the primary winding determines the amount of flux required since there must always be enough flux to induce the back emf in the primary.

To sum up, the back emf induced in the primary windings of the transformer is opposite in direction and almost equal in magnitude to the line voltage impressed on the primary. The back emf operates as a control when there are variations in the secondary load. This prevents the incoming line current from overloading the primary and burning it out.

There will always be enough current flow to set up this flux. At no load, this is the only current flowing and is called the *exciting current.* The exciting current may be as much as 40 percent of the full-load current in very small transformers, such as bell-ringing transformers. In distribution transformers, it may range up to 5 to 7 percent. In large power transformers, it usually is not more than 1 or 2 percent.

The exciting current is made up of two parts. One part is in phase with the impressed voltage and supplies the losses in the core caused by eddy current and hysteresis. The other part supplies the magnetizing current and is 90 degrees behind the impressed voltage. The magnetizing current is the part of the current that actually produces the flux.

A transformer does not generate electrical power. It simply transfers electrical power from one coil to another by magnetic induction. Since transformers are almost 100 percent efficient, a transformer can be defined as a device that transfers power from its primary circuit to its secondary circuit without loss. Transformers are classified as "step-up" or "step-down" only in relation to their effect on voltage. Transformers are designed for many different uses and frequencies.

Transformer Losses

When current flows in electrical equipment, there is always some loss. The losses in transformers are usually very small and are expressed as a percentage of the full-load rating. Losses may be classed as load losses and no-load losses. They may also be classed as primary losses, secondary losses, and core losses. The no-load loss is a core loss and is made up of two parts—eddy current loss and hysteresis loss.

The *eddy current* in the iron core of a transformer is an electric current induced in the core by the same magnetic flux that induces voltage in the metal conductors of the windings. The currents in the core are undesirable since they take energy from the circuit and produce no usable current. These eddy currents cause heat in the core where they flow, and the load is increased in primary and secondary windings.

The *hysteresis loss* results from magnetizing the iron core first in one direction and then in the opposite direction. Each time the polarity is reversed, some energy is used in overcoming the magnetism left in the core. The higher the frequency of the alternating current—that is, the more reversals on the magnetic field—the greater will be the hysteresis loss for a given field strength.

The *load or copper loss*, sometimes referred to as I^2R losses, occurs in the windings when current flows in them. This is because of the resistance in ohms of the copper to the flow of current through the windings, which shows up as heat in the windings. The copper loss in the primary or secondary is equal to the current shared times resistance in ohms, or I^2R.

Autotransformers

The autotransformer differs from other transformers in that it has *only one winding*, rather than two or more (see fig. 7). Part of this winding is used for both the primary and secondary, while the rest of the winding acts as either primary or secondary, depending on whether the autotransformer is used to step down or step up the voltage.

When the transformation ratio is comparatively small, usually less than four or five to one, and it is not necessary for the secondary circuit to be separated from the primary circuit, the autotransformer, as this tapped-reactance cell is called, is cheaper than the equivalent transformer with separate windings. It is much used for reducing the voltage applied to large AC motors during the starting period and commonly used as submersible electrical pump installations where the voltage at the well is slightly lower than the rated voltage of the electric motor powering the pump.

Autotransformers are sometimes used in power transmission system booster stations to step the voltage back up to transmission level. They are used to step voltage down to lower levels when the ratio is not large—such as the step-down from a high-voltage transmission level to a lower transmission level, such as from 132,000 volts down to 66,000 volts.

Three-Phase Delta and Wye Transformer Connections

The three-phase delta and wye transformer connections are also used in motors. The three-phase transformer is used when large power outputs are required. It may be a single transformer or three separate transformers and is generally connected in delta or wye.

The three-phase transformer core has less iron than that of three single transformers and therefore occupies less space and is lighter in weight. Figure 8 shows an elementary three-phase transformer that has three single-phase windings connectd in wye with their cores 120 degrees apart. The empty legs of each transformer are connected and form a common leg. The flux produced by the current in each of the windings is carried by this leg. The sum of the currents in the three windings is zero. Therefore, the

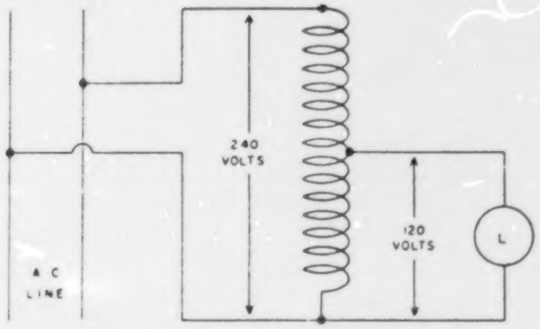


Fig. 7. The autotransformer uses one coil for both primary and secondary circuits. This one has all of the coil used as the primary and is connected across a 240-volt line. The lower half of the same coil is used as the secondary to furnish 120 volts for this second load (L).

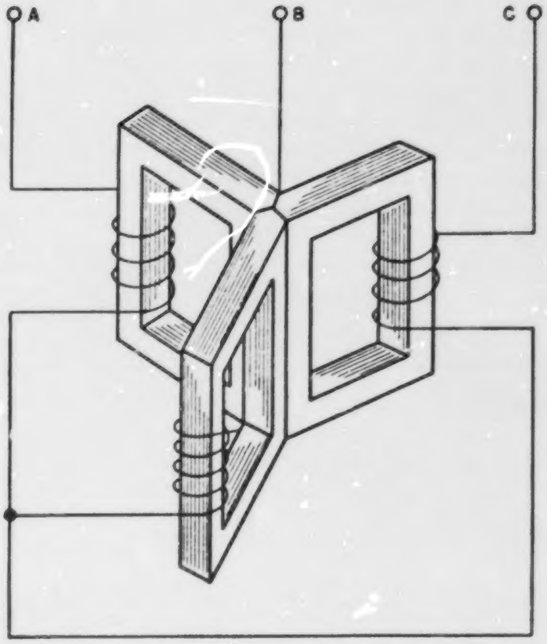


Fig. 8. Elementary three-phase transformer

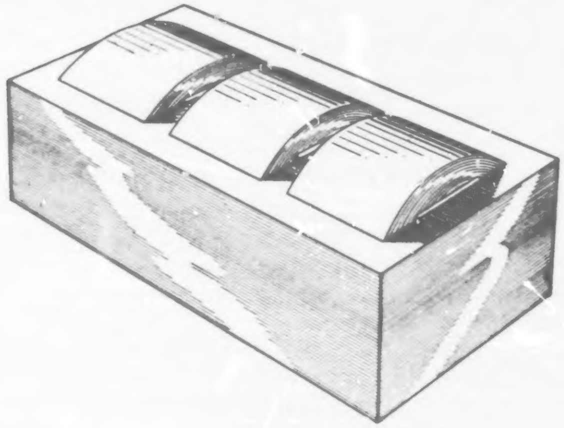


Fig. 9. Three-phase, shell-type transformer

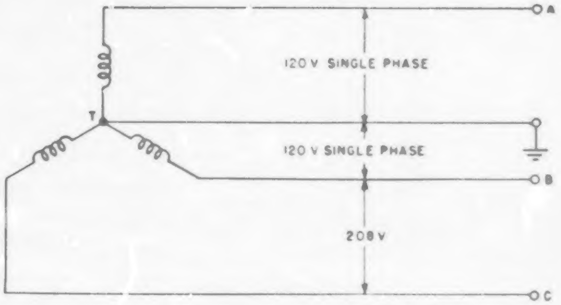


Fig. 10. Commercial three-phase voltage from power line

sum of the fluxes in the common leg must be zero, and no flux exists in this leg. Two legs of the transformer serve as a return path for the other. This is similar to the three-phase system where two of the windings serve as a return path for the other. The construction of this transformer is not practical, but it demonstrates the three-phase principle in a transformer.

Practical transformer construction uses the standard shell-type mounting shown in figure 9. This transformer is economical to construct and occupies less space than three single transformers. However, if one phase burns out, the whole unit must be replaced.

Commercial three-phase voltage from the power lines is generally 208 volts, and the standard values of single-phase voltage can be supplied from the line, as shown in figure 10. The windings represent the wye-connected transformer, which is generally outside installation. The three-phase connections are designated A, B, and C, and the single-phase connections are from A or B to ground. The three-phase transformer must be properly connected to these lines in order to operate.

Four of the most widely used connections (fig. 11) are the following:

1. Primary in delta and secondary in delta, or delta-delta
2. Primary in wye and secondary in wye, or wye-wye
3. Primary in wye and secondary in delta, or wye-delta
4. Primary in delta and secondary in wye, or delta-wye

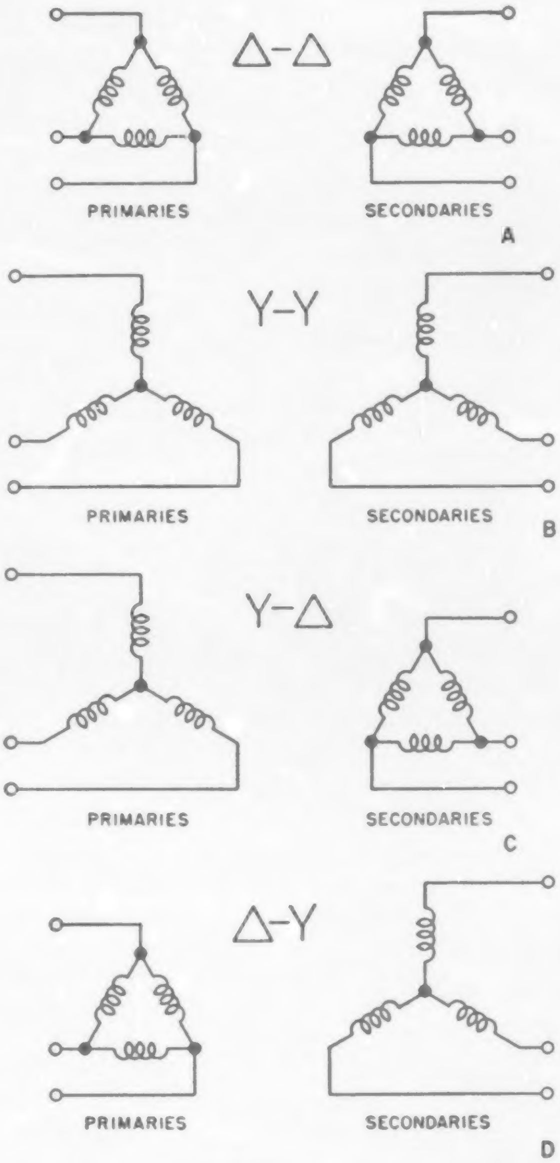


Fig. 11. Methods of connecting three-phase transformer

Of these four combinations, the fourth one, delta-wye, is used most extensively.

Regardless of the method of connection used, the secondary must be connected in the proper phase relationships. To determine these in a wye-connected transformer, the voltage is measured across two windings of the secondary (fig. 12A). The voltage from a to b should be equal to the voltage across either winding times the square root of 3. If the voltage reads the same as that across either winding, then one of the windings must be reversed. The third winding, cc_1, is then connected to a_1b_1, as shown in figure 12B, and the voltage across any two windings should equal the voltage of any one winding times $\sqrt{3}$. If the voltages do not read this value, the winding cc_1 must be reversed.

To determine the proper phase relationships in a delta-connected secondary, the voltage is measured across two coils of the secondary (fig. 12C). The voltage from a to b_1 should equal the voltage across either coil. If it does not, either one of the windings must be reversed. The winding cc_1 is then

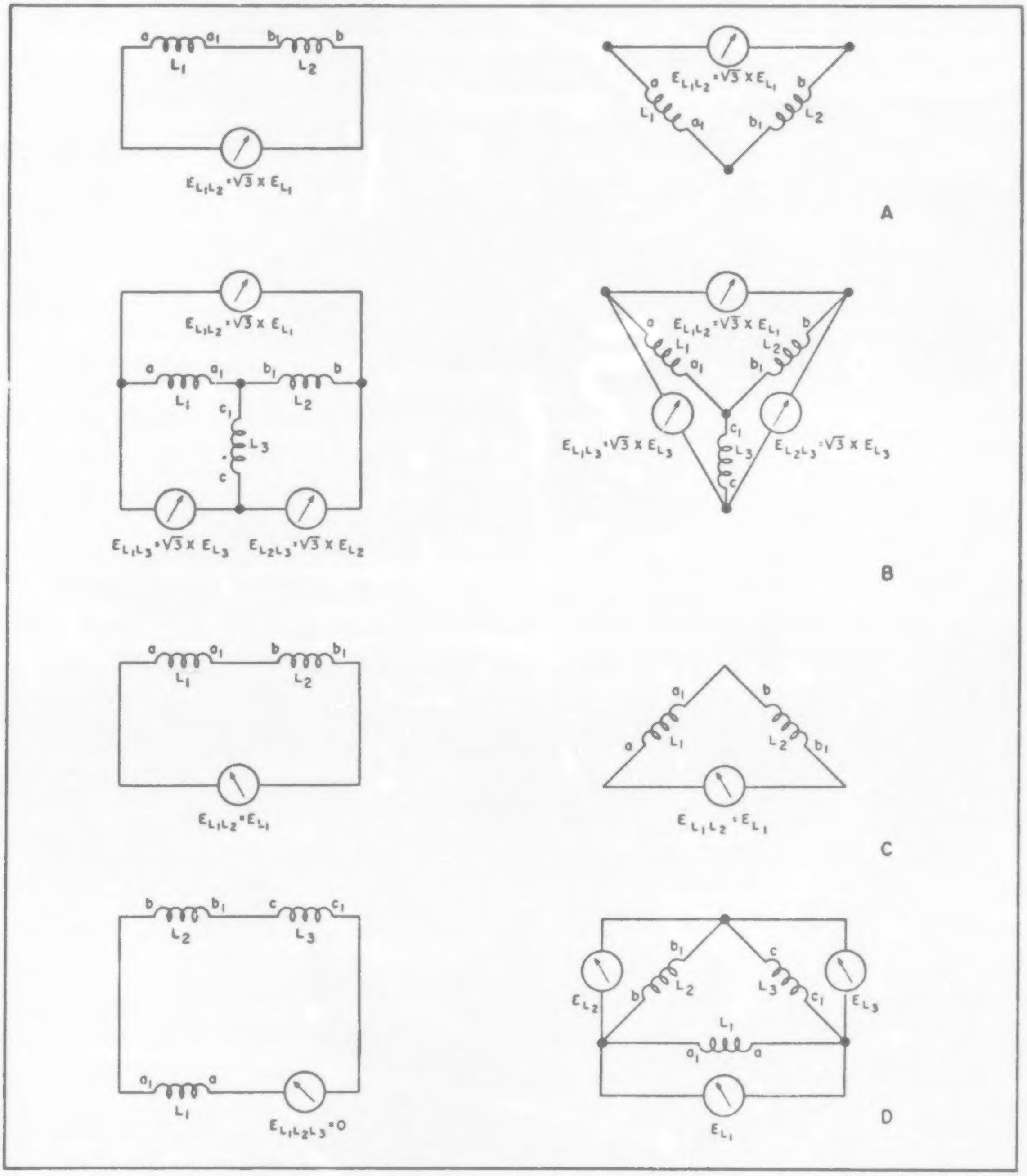

a
a1
b1
b
L1
L2
EL1L2=√3 x EL1
A
a
a1
b1
b
c1
c
L1
L2
L3
EL1L2=√3 x EL1
EL1L3=√3 x EL3
EL2L3=√3 x EL2
EL2L3=√3 x EL3
B
a
a1
b
b1
L1
L2
EL1L2=EL1
C
b
b1
c
c1
a1
a
L1
L2
L3
EL1L2L3=0
EL1
EL2
EL3
D

Fig. 12. Phasing of transformers for delta or wye connection

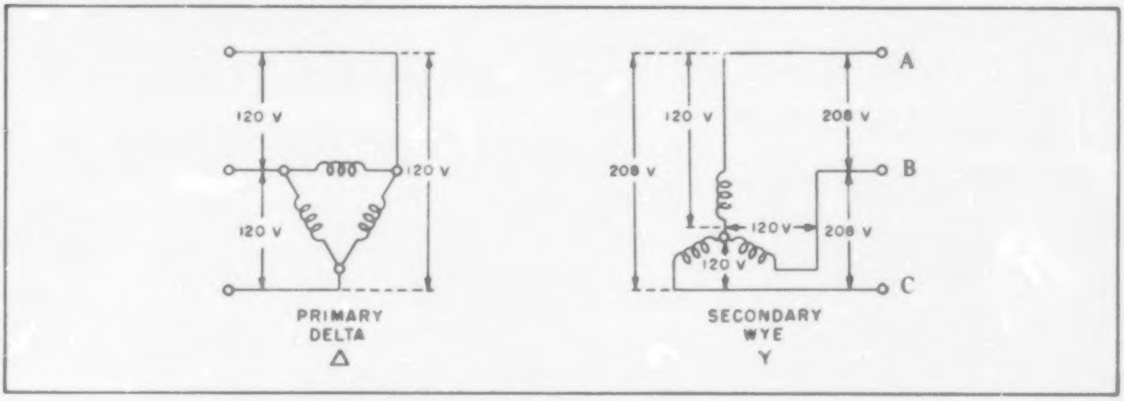


Fig. 13. Delta-wye transformer connection

connected to b_1, as shown in figure 12D. The voltage across the three coils should then measure zero. If the voltage does not read zero, then the winding cc_1 must be reversed. The open ends, a and c_1, are then connected, and the transformer has the proper phase relationships for delta connection.

The wye-wye (Y-Y) connection has the same volts per turn ratio between primary and secondary as that of an individual transformer. When using this connection, unless the primary neutral point is connected to the line neutral point, a "floating neutral" results with an appreciable loss of power in some installations.

The voltage output of the delta-delta is also dependent on the turn ratio of the primary and secondary. Its greatest advantage is its ability to operate as a V (or open delta) circuit if one winding become inoperative.

The delta-wye connection is generally used for radio power transformers. This connection, unlike the wye-wye connection, is not affected by a floating neutral point. It also has a higher voltage ratio between primary and secondary than either the delta-delta or the wye-wye connection. This is because the voltage across the two windings of the wye is equal to the $\sqrt{3}$ times E_L. For example, the delta primary is connected across a 208-volt, three-phase system (fig. 13), and the voltage across any phase is 120 volts. The voltage across any winding of the secondary will therefore be 120 volts, but the voltage across two of the windings will be

$$\sqrt{3} \times E_L = E_{sec}$$

$$1.73 \times 120 = 208 \text{ volts} = E_{sec}$$

Because of this, the delta-wye connection permits cheaper construction of the transformer in high-voltage installations. The wye-delta connection is the opposite of the delta-wye connection and is often used for step-down voltages.

The voltage across A and B (fig. 13) is equal to 208 volts. The ratio between line voltage and secondary voltage in the delta-wye transformer connection is not the transformer turn ratio, but $\sqrt{3}$ times the turn ratio. The output voltage across any two windings is greater than that of a single winding. Therefore, the single winding need be insulated for only $E_y/\sqrt{3}$ volts. For example, if the voltage across two windings of the secondary is 20,000 volts, the voltage across the one phase is $E_y/\sqrt{3} = 20{,}000/1.73 =$ 11,600 volts (approx).

Exercise

1. Define a *transformer.*
2. Name the transformer winding that is connected to the source of power and the one that is connected to the load.
3. What is the connection between the coil windings of a transformer?
4. Explain why the cores of transformers are made up of thin strips of metal with insulating material between them.
5. Explain the difference between a step-up transformer and a step-down transformer.
6. What is the principal use of autotransformers in relation to motors?
7. What is the power relationship between the primary and secondary windings of a transformer under load?

G-3

Theory of Electric Motors

Objectives: After completing this assignment, you will be able to—

1. state the purpose of the generator and the electric motor;
2. tell what makes the armature of the electric motor rotate;
3. discuss torque and back emf;
4. define *inrush current;*
5. state the operating principle of the induction motor;
6. describe the rotor of an induction motor;
7. define *slip;* and
8. explain the principle of operation of the synchronous motor.

The purpose of the generator is to change mechanical energy into electrical energy. The purpose of the electric motor is to change electrical energy into mechanical energy. In mechanical design, the generator and the simple DC motor do not differ essentially from each other. Each has an armature rotating in a magnetic field.

In the generator, the armature is caused to rotate by some external mechanical force, and electricity is generated in the armature coils. In the simple DC motor, the armature is an electromagnet, cutting lines of force produced by another electromagnet serving as a field. When current from a generator or other source is led to the motor, two magnetic fields are produced, one in the armature and one in the field magnet. It is the reaction between these two magnetic fields—the magnetic flux of the field poles—that causes the armature of the electric motor to rotate.

Motor Principle

A magnetic field forms between unlike poles. A conductor carrying a current produces a magnetic field around it. In figure 1, examples of both these magnetic fields are shown. In the magnetic field between unlike poles, the direction of flux is always from north to south. In a conductor carrying a current, the direction of flux depends on the direction of current in the conductor (left-hand rule for conductors).

Motor principle can be explained by showing what happens when a current-carrying conductor is placed in the magnetic field between unlike poles, as pictured in figure 2. On the side of the conductor where the flux direction of both magnetic fields is the same, the lines are crowded together, strengthening the field on this side of the conductor and weakening it on the other. Because they are crowded together and distorted, the lines of force on this strong side will tend to push the conductor toward the weak side.

Looking at figure 2A, it might seem that the conductor is moving downward and squeezing the lines of force together. However, these lines of force appear thus because they are the flux from both magnetic fields crowded together. To realize how they force the

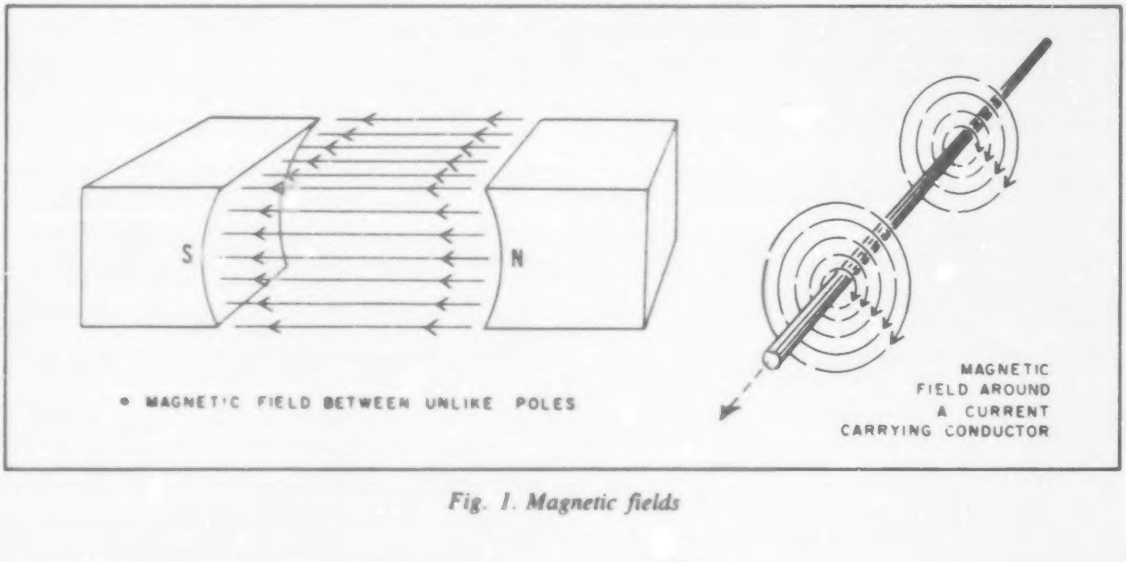

S
N
• MAGNETIC FIELD BETWEEN UNLIKE POLES
MAGNETIC FIELD AROUND A CURRENT CARRYING CONDUCTOR

Fig. 1. Magnetic fields

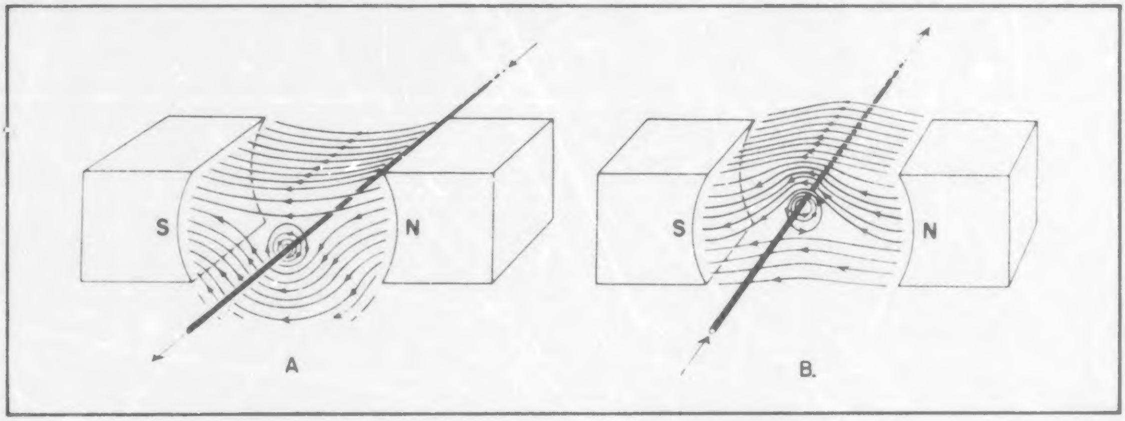


Fig. 2. A current-carrying conductor in a magnetic field

conductor upward, imagine them as elastic rubber bands, which, having been pushed out of shape, will tend to straighten and spring back in the opposite direction, thus forcing the conductor upward.

In figure 2B, with current in the conductor flowing away from the viewer, the magnetic flux around it is in the opposite direction from that in figure 2A, and the conductor will be forced downward. The operation of the electric motor depends on this fundamental principle—that *a conductor carrying a current in the magnetic field tends to move at right angles to that field.*

A definite relationship exists between the direction of the lines of force in a magnetic field, the direction of current flow in the conductor, and the direction in which the conductor tends to move. The **right-hand rule for motors** is useful in learning this relationship. Extend the thumb, forefinger, and middle finger of the right hand at right angles to each other. Point the forefinger in the direction of magnetic flux, with the middle finger pointing in the direction of current flow. The thumb will then point in the direction in which the conductor will move, as shown in figure 3.

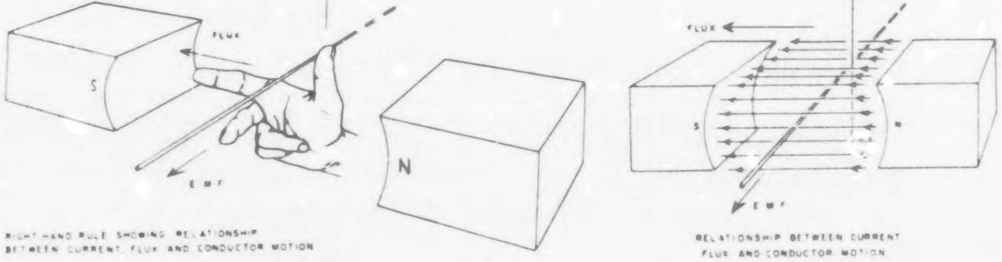
Attraction and Repulsion

Now, instead of a straight conductor carrying a current, mount an electromagnet on an axis so that it is free to rotate between the poles of a magnet, as in figure 4. The poles of the armature (the turning electromagnet) will be attracted by the opposite poles of the permanent magnet, causing the armature to rotate in a counterclockwise direction.

Polarity at the start of rotation is as shown in figure 4A. When the two sets of opposite poles are nearest each other, the armature would stop turning—except that inertia carries the poles of the armature slightly beyond the poles of the permanent magnet.

We know that the polarity of the electromagnet can be changed by changing the direction of current flow in its coils. By changing the direction of current flow in the rotating magnet at the very instant that the two sets of opposite poles are nearest each other, we again have like poles repelling each other, and opposite poles attracting each other, as in figure 4B.

The stationary poles will then continue to drive the rotating electromagnet through a second 180 degrees of rotation through their attraction and repulsion. The direction of current flow in the electromagnet is changed at just the right instant through the use of a commutator and brushes in DC motors, and through the use of slip rings in AC motors.


MOTION
FLUX
S
E M F
N
RIGHT HAND RULE SHOWING RELATIONSHIP BETWEEN CURRENT, FLUX AND CONDUCTOR MOTION
MOTION
FLUX
S
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RELATIONSHIP BETWEEN CURRENT FLUX AND CONDUCTOR MOTION

Fig. 3. Right-hand rule for motors

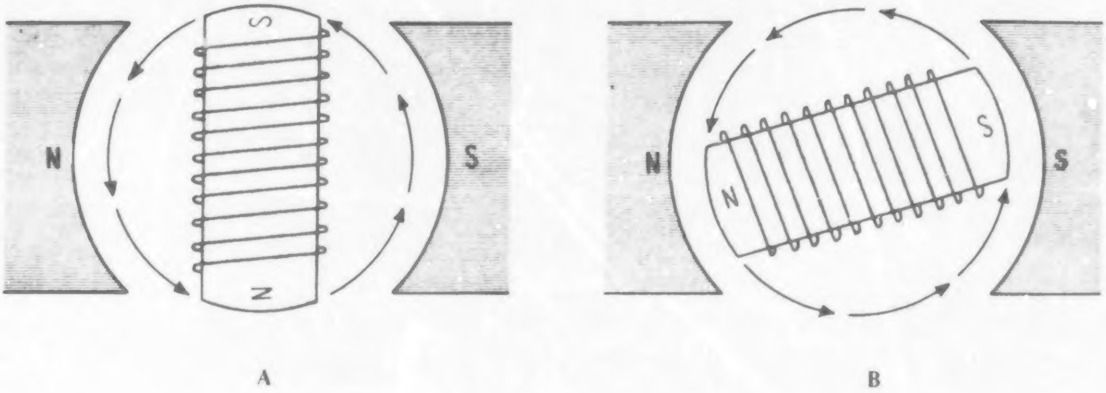


Fig. 4. Development of torque—attraction and repulsion

Torque

To more fully understand motor principle, another force must be considered, in addition to that of attraction and repulsion. Figure 2 showed that a current-carrying conductor placed in a magnetic field tends to move at right angles to the field. Figure 5A shows a current-carrying conductor shaped in a loop and placed in a magnetic field. Direction of current flow is indicated in this way: the dot represents current traveling toward the viewer (point of an arrow), and the cross represents current traveling away from the viewer (cross section of the feathered end of an arrow).

Thus, in figure 5A, the left side of the loop will be forced upward, the right side will be forced downward, and the loop will rotate. When the loop has rotated 180 degrees, the direction of current in it is reversed and it will continue to turn.

Figure 5B shows a cross section of an armature containing several loops. The torque in this armature is developed in substantially the same way. That is, the direction of current in each loop changes at precisely the moment when it would otherwise no longer be thrust forward in the magnetic flux. The *torque*, or *turning force*, exerted in a magnetic field is proportional to the strength of the magnetic field, the length of the field and the number of turns in the conductor, and the strength of the current flowing in the conductor. Torque is the ability of the rotor in an electric motor to carry its load. It is based on the attracting and repelling forces of like and unlike poles and the movement of a current-carrying conductor through a magnetic field.

Back Emf

When a conductor cuts lines of force, a voltage is induced in the conductor. When the armature of a wound motor (either AC or DC) is spinning through a magnetic field, voltage is applied to this armature in order to develop torque. In addition, an emf is induced in this armature by the magnetic field through which it is spinning. The magnetic poles set up in the rotor sweep across the field windings and induce an emf in them. The induced, or back, emf is in the opposite direc-

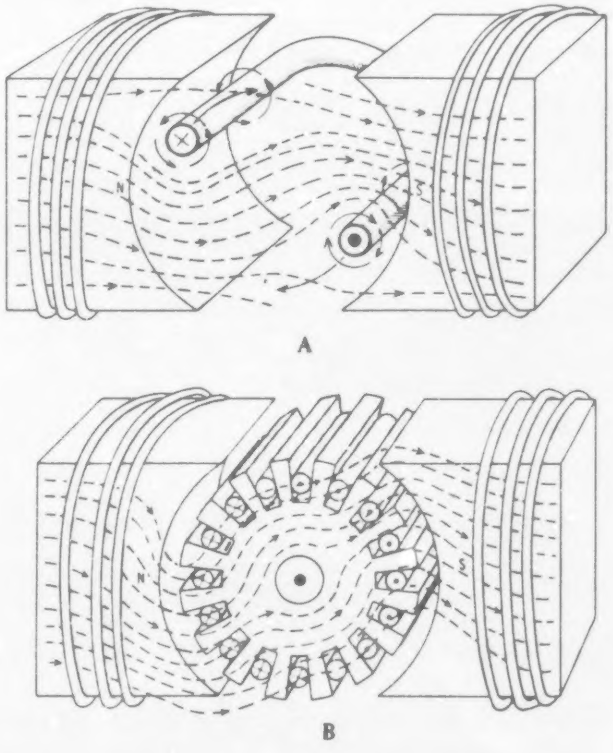


Fig. 5. Development of torque—current-carrying conductor in a magnetic field

tion of the *applied emf*, which causes the motor to run. The back emf is in proportion to the speed of rotation and, if it were not opposite the direction of the applied emf, would cause the motor to run faster.

When a motor is started, the back emf is zero. As the motor speed increases, the back emf increases, until it is almost equal to the applied emf. At full motor speed, it is about 90 percent of the applied emf. At the instant the motor starts, when the back emf is zero, a large current, called *inrush current*, rushes through the motor windings. Because of low coil resistance of some large motors, a starting rheostat or resistance is used to limit the heavy starting current. This resistance limits the inital surge of current and is then reduced in steps as the motor gains speed and back emf increases, limiting the flow of line current through the motor. When the motor is at about full rpm load, all of the resistance is cut out of the circuit, and the back emf controls the incoming line current through the motor windings. Note: torque and current decrease the speed.

AC Induction Motors

Of all AC motors, the induction motor is the most widely used. Its design is simple and its construction rugged. The induction motor is particularly well adapted for constant speed applications, and because it does not use a commutator, most of the troubles encountered in the operation of DC motors are eliminated.

An induction motor can be either a single-phase or a polyphase machine. The operating principle is the same in either case and depends on a revolving, or rotating, magnetic field to produce torque. The key to understanding the induction motor is a thorough comprehension of the **rotating magnetic field.**

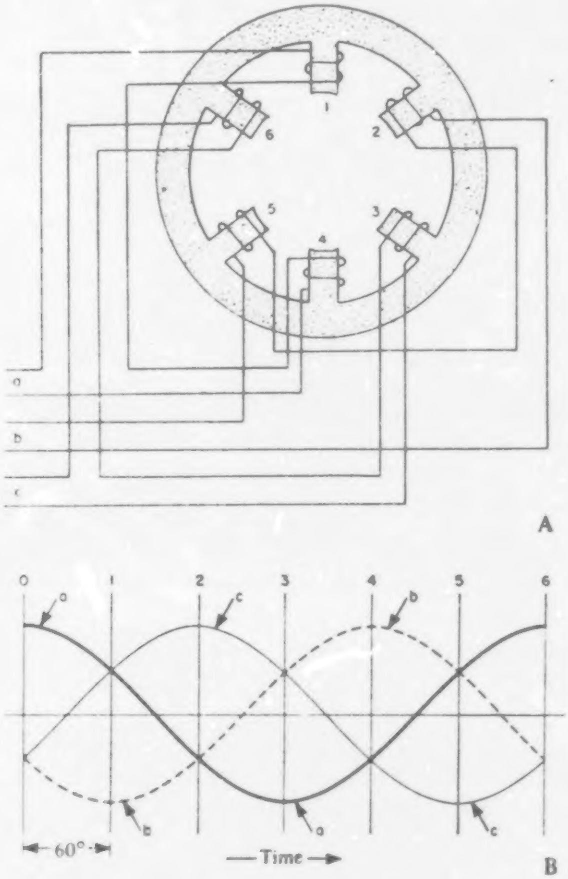


Fig. 6. A rotating magnetic field developed by application of three-phased voltages

Consider the field structure of figure 6A where the poles have windings that are energized by three AC voltages, a, b, and c. These voltages have equal magnitude but differ in phase, as shown in figures 6B and 7.

At the instant of time shown as 0, the resultant magnetic field produced by the application of the three voltages has its greatest intensity in direction extending from pole 1 to pole 4. Under this condition, pole 1 can be considered as a north pole and pole 4 as a south pole.

At the instant of time shown as 1, the resultant magnetic field will have its greatest intensity in the direction extending from pole 2 to pole 5. In this case, pole 2 can be considered as a north pole and pole 5 as a south pole. Thus, between instant 0 and instant 1, the magnetic field has rotated clockwise.

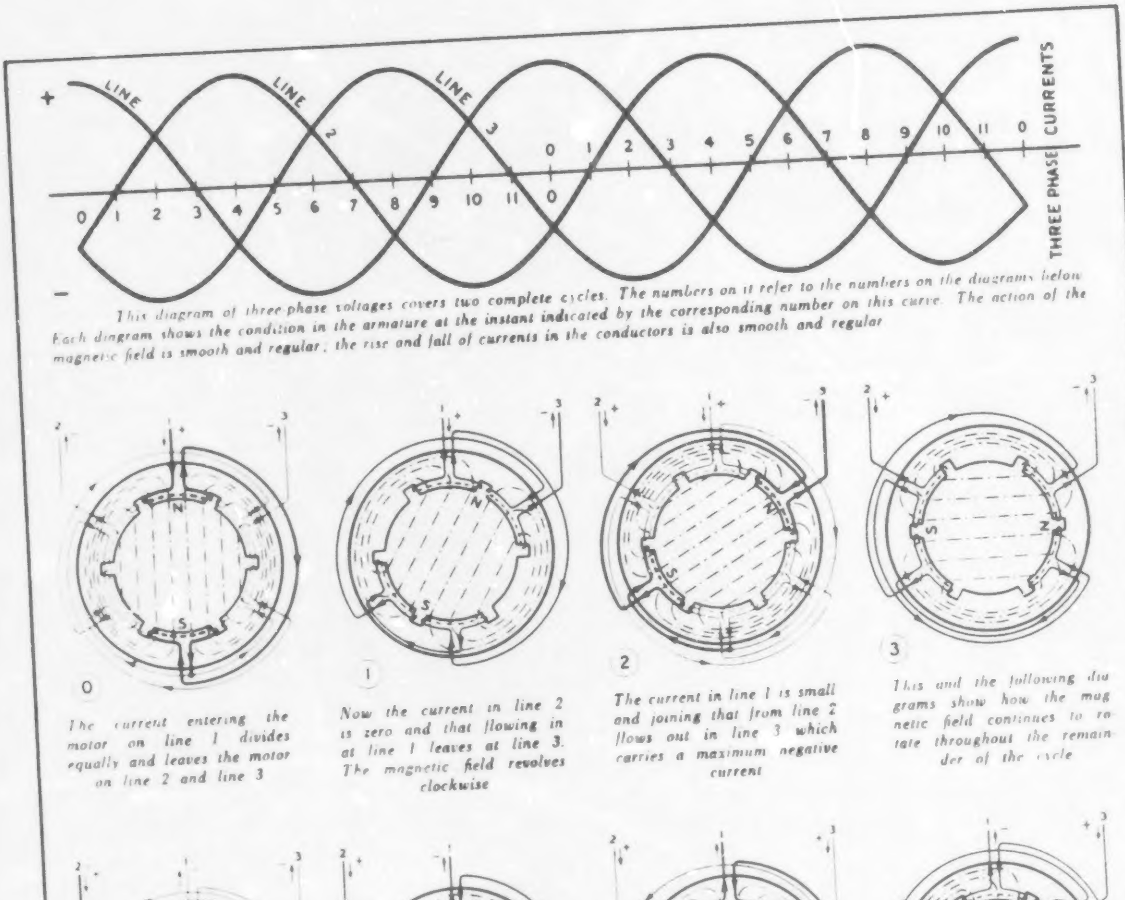
At time 2, the resultant magnetic field has its greatest intensity in the direction from pole 3 to pole 6, and it is apparent that the resultant magnetic field has continued to rotate clockwise.

At instant 3, poles 4 and 1 can be considered as north and south poles, respectively, and the field has rotated still farther.

At later instants of time, the resultant magnetic field rotates to other positions, while traveling in a clockwise direction. A single revolution of the field occurs in one cycle. If the exciting voltages have a frequency of 60 cycles per second, the magnetic field makes 60 revolutions per second, or 3,600 revolutions per minute. This speed is known as the *synchronous speed of the rotating field.*

In an induction motor, the stationary part of the machine is called a *stator*, and the rotating member is called a *rotor*. Instead of salient poles in the stator, as shown in figure 6A, distributed windings are used. These windings are placed in slots around the periphery of the stator.

To determine the number of poles on



This diagram of three-phase voltages covers two complete cycles. The numbers on it refer to the numbers on the diagrams below. Each diagram shows the condition in the armature at the instant indicated by the corresponding number on this curve. The action of the magnetic field is smooth and regular; the rise and fall of currents in the conductors is also smooth and regular

0 The current entering the motor on line 1 divides equally and leaves the motor on line 2 and line 3

1 Now the current in line 2 is zero and that flowing in at line 1 leaves at line 3. The magnetic field revolves clockwise

2 The current in line 1 is small and joining that from line 2 flows out in line 3 which carries a maximum negative current

3 This and the following diagrams show how the magnetic field continues to rotate throughout the remainder of the cycle

Fig. 7. These twelve diagrams show the electric and magnetic conditions in a two-pole, three-phase motor at the end of twelve equal parts of one cycle.

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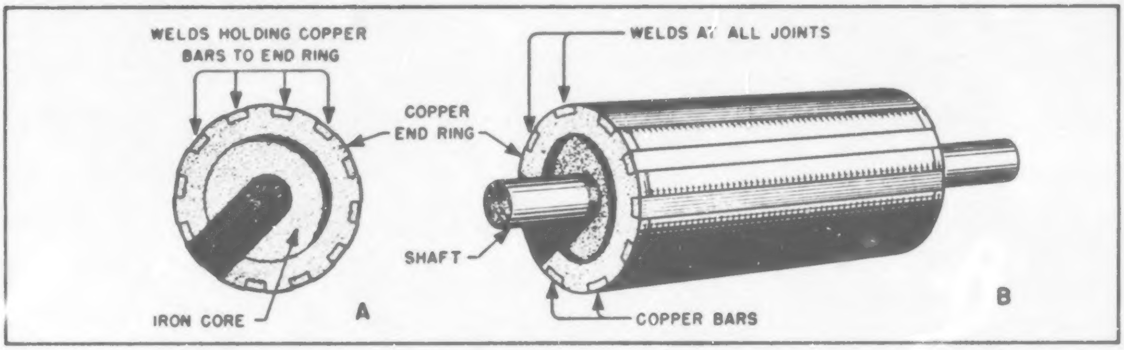

Fig. 8. Squirrel-cage rotor

an induction motor, check the nameplate on the machine. The nameplate usually gives the number of poles and the speed at which the motor is designed to run. This rated, or asynchronous, speed is slightly less than the synchronous speed. To determine the number of poles per phase on the motor, multiply the frequency by 120, and divide this by the rated speed:

$$P = 120 \times f/N$$

Where: P = number of poles per phase
f = frequency, in cycles per second (hertz)
N = rated speed, in rpm
120 = constant (half cycle)

The result will be very nearly equal to the number of poles per phase. For example, consider a 60-cycle, three-phase machine with a rated speed of 1,750 rpm. In this case,

$$P = 120 \times 60/1{,}750$$
$$= 7{,}200/1{,}750 = 4.1$$

Therefore, the machine has four poles per phase. If the number of poles per phase is given on the nameplate, the synchronous speed is equal to 7,200 divided by 4, or 1,800 rpm.

The rotor of an induction motor consists of an iron core having longitudinal slots around its circumference in which heavy copper or aluminum bars are embedded. These bars are welded to a heavy ring of high conductivity on either end. This composite structure is sometimes called a *squirrel-cage rotor* (fig. 8), and motors containing such a rotor are called squirrel-cage induction motors.

Slip

When the rotor of an induction motor is subjected to the revolving magnetic field produced by the stator windings, a voltage is induced in the longitudinal bars. The induced voltage causes a current to flow through the bars. This current, in turn, produces its own magnetic field, which combines with the revolving field in such a way as to cause the rotor to assume a position in which the induced voltage is minimized. As a result, the rotor revolves at very nearly the synchronous speed of the stator field, and the difference in speed is just enough to induce enough current in the rotor to overcome the mechanical and electrical losses in the rotor.

If the rotor were to turn at the same speed as the rotating field, the rotor conductors would not be cut by any magnetic lines of force, no emf would be induced in them, no current could flow, and there would be no torque. The rotor would then slow down.

For this reason, there must always be a difference in speed between the rotor and rotating field. This difference in speed is called *slip* and is expressed as a percentage of the synchronous speed. For example, if the rotor turns at 1,750 rpm and the synchronous speed is 1,800 rpm, the difference in speed is 50 rpm. The slip is then equal to 50/1,800, or 2.78 percent.

Single-Phase Machines

The previous discussion has applied only to polyphase machines. In a single-phase machine, the field, instead of rotating, merely *pulsates*, and no rotation of the rotor takes place. However, a single-phase pulsating field may be visualized as two rotating fields revolving at the same speed but in opposite directions. Therefore, the rotor will revolve in either direction at nearly synchronous speed provided it is given an initial impetus in either one direction or the other.

The exact value of this initial rotational velocity varies widely with different machines, but a velocity higher than 15 percent of the synchronous speed is usually enough to cause the rotor to accelerate to rated speed. A single-phase motor can be made self-starting if means can be provided to give the effect of a rotating field.

The first effort in the development of a self-starting, single-phase motor was the *shaded-pole induction motor* (fig. 9). This machine has salient poles, with a portion of each pole encircled by a heavy copper ring. The presence of the ring causes the magnetic field through the ringed portion of the pole face to lag appreciably behind that through the other part of the pole face. The net effect is the production of a slight component of rotation of the field that is sufficient to cause the rotor to revolve. As the rotor accelerates, the torque increases until the rated speed is obtained. Such motors have low starting torque and find their greatest application in small fan motors where the initial torque required is low.

Various types of self-starting motors have been made. Such motors have a starting winding displaced 90 electrical degrees from the main, or running, winding. In some types, the starting winding has a fairly high resistance, which causes the current in this winding to be out of phase with the current in the running winding. This condition produces, in effect, a rotating field, and the rotor revolves. A centrifugal switch is used to disconnect the starting winding automatically after the rotor has reached about 25 percent of its rated speed.

With the development of high-capacity electrolytic capacitors, a variation of the split-phase motor, known as the *capacitor-start motor,* has been made. Nearly all fractional horsepower motors in use today on refrigerators, oil burners, and other similar appliances are of this type. In this adaptation, the starting winding and the running winding have the same size and resistance value, and the phase shift between currents of the two windings is obtained by means of capacitors connected in series with the starting winding.

Capacitor-start motors have a starting torque comparable to their torque at rated speed. They can be used in applications where the initial load is heavy. Again, a centrifugal switch is required for disconnecting the starting winding when the rotor speed is about 25 percent of the rated speed.

Although some single-phase induction motors are rated as high as 2 hp, the major field of application is 1 hp, or less, at voltage ratings of 115 volts for the smaller sizes and 110 to 220 volts for ¼ hp and up. For still larger power ratings, polyphase motors are generally used, because they have excellent starting torque.

The **direction of rotation** of a three-phase induction motor can be changed by simply reversing two of the leads to the motor. The same effect can be obtained by reversing connections to one phase in a two-phase motor. In a single-phase motor, reversing connections to the starting winding will reverse the direction of rotation. Most single-phase motors designed for general application have provision for readily reversing connections to the starting winding. Nothing can be done to a shaded-pole motor to reverse the direction of rotation because the direction is determined by the physical location of the copper shading ring.

If, after starting, one connection to a three-phase motor is broken, the motor will continue to run but will deliver only one-third the rated power. Also, a two-phase motor will run at one-half its rated power if one phase is disconnected. Neither motor will start under these abnormal conditions.

Synchronous Motor

The synchronous motor is one of the principal types of AC motors. Like the induction motor, the synchronous motor makes use of a rotating magnetic field. Unlike the induction motor, however, the torque developed does not depend on the induction of currents in the rotor.

Briefly, the principle of operation of the synchronous motor is as follows. A multiphase source of alternating current is applied to the stator windings, and a rotating magnetic field is produced. A direct current is applied to the rotor windings, and another magnetic field is produced. The synchronous motor is so designed and constructed that these two fields react on each other in such a way that the rotor is dragged along and rotates at the same speed as the rotating magnetic field produced by the stator windings.

The operation of a simple synchronous motor is shown in figure 10. Assume that poles A and B are being rotated by some mechanical means in order to produce a rotating magnetic field. The rotating poles induce poles of opposite polarity, and forces of attraction exist between corresponding north and south poles. Thus, as poles A and B rotate, the rotor is applied to the rotor shaft, and the rotor axis will

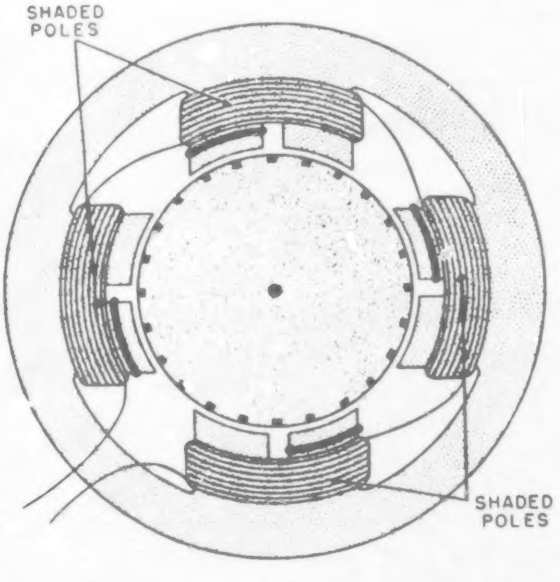

Fig. 9. Shaded pole

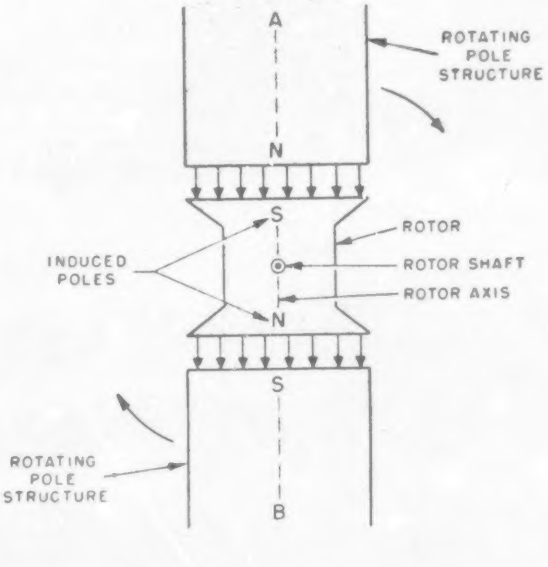

Fig. 10. Simple synchronous motor

momentarily fall behind that of the rotating field but will thereafter continue to rotate with the field at the same speed as long as the load remains constant. If the load is made too large, the rotor will pull out of synchronism with the rotating field at the same speed. The motor is then said to be overloaded.

However, such a simple motor as that shown in figure 10 is never used, for two reasons:

1. The idea of using some mechanical means of rotating the poles is impractical because another motor would be required to perform this work. Also, such an arrangement is unnecessary because a rotating magnetic field can be produced electrically by using phased AC voltages (fig. 11). In this respect, the synchronous motor is similar to the induction motor.

2. The magnitude of the induced poles in the rotor shown in figure 10 is so small that sufficient torque cannot be developed for most practical loads. To avoid such a limitation on motor operation, a winding is placed on the rotor, and this winding is energized with direct current. A rheostat placed in series with the DC source provides the operator of the machine with a means of varying the strength of the rotor poles, thus placing the motor under control for varying loads.

If a synchronous motor is driven by an external power source and the excitation, or voltage applied to the rotor, is adjusted to a certain value called *100 percent excitation*, no current will flow from or to the stator winding. In this case, the voltage generated in the stator windings by the rotor, or back emf, exactly balances the applied voltage. However, if the excitation is reduced below the 100 percent value, the difference between the back emf and the applied voltage produces a reactive component of current that lags the applied voltage. The machine then acts as an inductance. Similarly, if the excitation is increased above the 100 percent value, the reactive component leads the applied voltage, and the machine acts as a capacitor. This feature of the synchronous motor permits use of the machine as a power-factor correction device. When so used, it is called a *synchronous capacitor*.

When used as a synchronous capacitor, the motor is connected on the AC line in parallel with the other motors on the line and run either without load or with a very light load. The rotor field is overexcited just enough to produce a leading current that offsets the lagging current of the line. Unity power factor results.

The synchronous motor can be made to produce up to 80 percent leading power factor. However, because a leading power factor on a line is just as bad as a lagging power factor, the synchronous motor is regulated to produce just enough leading current to compensate for lagging current in the line.

The synchronous motor is not a self-starting motor. The rotor is heavy, and from a dead stop it is impossible to bring the rotor into magnetic lock with

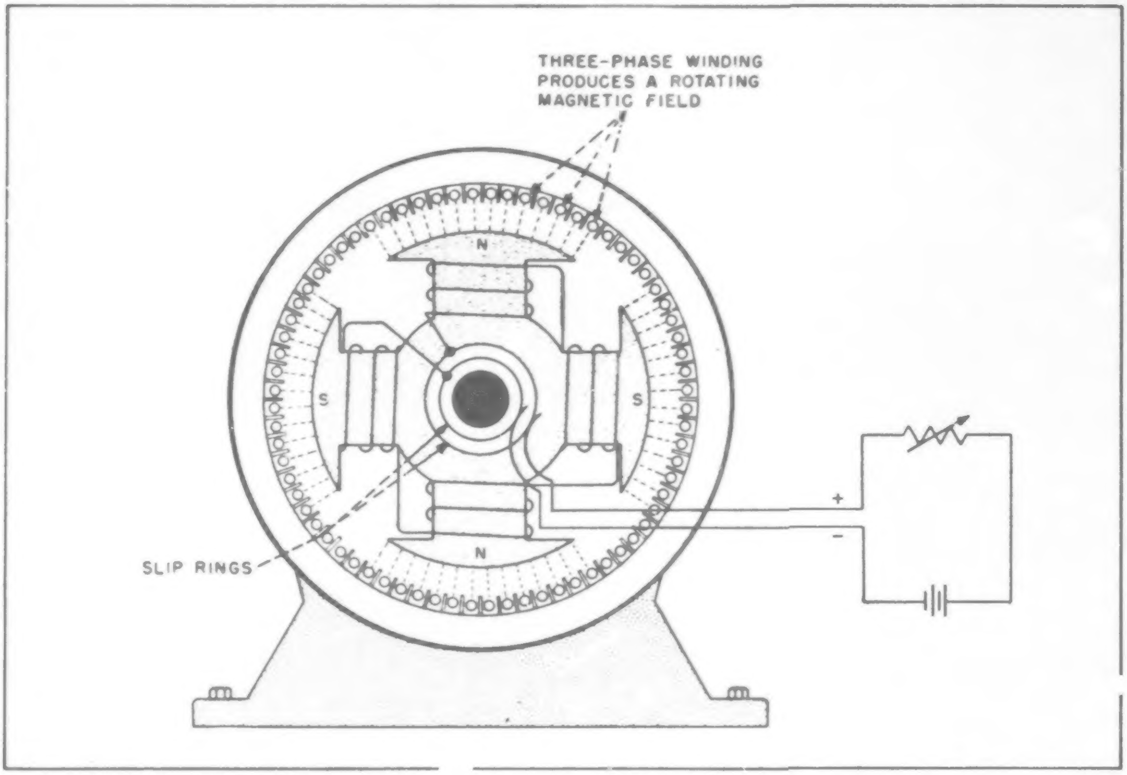

Fig. 11. Synchronous motor

the rotating magnetic field. For this reason, all synchronous motors have some kind of starting device.

A simple starter is another motor, either AC or DC, that brings the rotor up to about 90 percent of its synchronous speed. The starting motor is then disconnected, and the rotor locks in step with the rotating field.

Another starting method is a second winding of the squirrel-cage type on the rotor. This induction winding brings the rotor almost to synchronous speed. Then, when the direct current is connected to the rotor windings, the rotor pulls into step with the field. The latter method is the one more commonly used.

Exercise

1. What is the purpose of the generator and of the electric motor?
2. What causes the armature of the electric motor to rotate?
3. What is torque, in relation to the magnetic field?
4. In what direction is the *back emf*?
5. What happens to the back emf as the motor speed increases?
6. What is *inrush current?*
7. What does the operating principle of the induction motor depend on?
8. What does the rotor of an induction motor consist of?
9. What is *slip?*
10. Explain the principle of operation of the synchronous motor.

Section

H

Theory and Measurement of Alternating Current

- H-1. Inductance and Its Reactance to Alternating Current
- H-2. Capacitance and Its Reactance to Alternating Current
- H-3. Alternating-Current Principles

H-1

Inductance and Its Reactance to Alternating Current

Objectives: After completing this assignment, you will be able to—

1. define *inductance;*
2. write the formulas for calculating the total inductance of inductors in series and in parallel;
3. write the formula for calculating the ohmic value of inductive reactance; and
4. tell why maximum power is used in a pure resistive AC circuit.

Inductance

In an AC circuit, the effect of electrical inertia, or inductance, is ever-present, since by definition an alternating current is one constantly changing in magnitude and periodically changing direction. Thus, if the current in a circuit is increasing, the inductance is defined as that property of the circuit that tends to prevent the increase. If the current is decreasing, the inductance of the circuit tends to prevent the decrease. The greater the inductance of the circuit, the greater the opposition to a change in current. *Inductance* is that property of an electrical circuit that tends to prevent a change in current.

In AC circuits, an opposition to the flow of current other than the DC resistance of the circuit is always present. This additional opposition is caused by a counter, or back, electromotive force (emf), so named to distinguish it from the applied voltage, which is the original flow. Back emf, or counter emf, is analogous to the force that opposes a change in motion of a mass. Generally speaking, the velocity of a mass cannot be changed instantaneously, whether that mass is an automobile, an electron, or an electrostatic charge.

In an electric circuit, the counter emf (cemf) is an induced emf or voltage. This voltage is induced in conductors of the circuit not by means of an external magnetic field, as in the case of the simple two-pole generator, but by means of the magnetic field already surrounding any conductor carrying a current. Any change in current changes the intensity of this magnetic field, and the resultant emf induced, the counter emf, is a self-induced voltage.

Thus, the property of a circuit that produces such an emf is called *self-inductance*. However, for all practical purposes only those elements designed to make use of this property to advantage are known as inductances or inductors. Also, counter emf is present in any AC circuit, but its effect is negligible in a circuit of moderate power, such as an electric lamp, which uses almost pure resistance as a load. However, its effect is considerable in circuits (even of very low power) that use an inductance as part of the load, such as the primary of the power transformer in an ordinary radio receiver.

Generation of Counter Emf, Lenz's Law

In the simple generator, motion either of the conductor or of the magnet was necessary to an induced emf. In self-inductance, the equivalent of motion—that is, a change in flux density of the magnetic lines of force about a conductor—is caused by the rise or fall of the current since the intensity of a magnetic field about a conductor is directly proportional to the current through the conductor. The force setting up the flux lines is equal to $.4\pi NI$. Since $.4\pi$ is a constant, the factor NI is called the ampere-turns. Any change in current changes the factor NI, or ampere-turns, and, accordingly, the flux density. Thus, self-inductance is present constantly in an AC circuit because current is constantly changing, but it is present in a DC circuit only at the moments of closing or opening the circuit.

That the emf self-induced in a conductor carrying current is a counter emf was deduced by H. F. E. Lenz from the principle of the conservation of energy. If the emf self-induced was not a counter emf, then an increase of current would aid the applied voltage, and this increase in applied voltage would in turn tend to increase the current. This process would continue, of course, until current reached an infinite amount, a condition not possible in the physical universe. Lenz's law states that *an induced emf always has such a direction as to oppose the action that produces it*. Thus, when a current flowing through a circuit is varying in magnitude, it produces a varying magnetic field, which sets up an induced emf that opposes the current change producing it. Or, when the current in a circuit is increasing, the induced emf opposes the applied voltage and tends to keep the current from increasing. Also, when the current is decreasing, the induced emf aids the line voltage and tends to keep the current from decreasing.

The effect of counter emf may be observed experimentally in that an alternating current through an inductor is opposed by a force much greater than its simple DC resistance. For example, the DC resistance of the primary of an ordinary power transformer used in a typical radio receiver is about 5 ohms. As in figure 1, this primary is connected directly to the 110-volt, AC outlet in the home. From Ohm's law: I = E/R = 110/5 = 22 amp.

Thus, the current is calculated to be 22 amp but, when actually measured, is found to be about 1 amp. Some opposition other than the 5-ohm resistance is present in an AC circuit. This opposition is the counter emf. If by mistake such a radio set is connected to a 110-volt DC line, the current through the primary of the transformer is 22 amp, and the transformer burns up. Hence, Ohm's law as stated for DC circuits must be modified to include this effect of electrical inertia present in AC circuits.

Measurement of Inductance: The Henry

The unit of measurement of inductance is the henry, named after Joseph Henry, the codiscoverer with Faraday of the principle of electromagnetic induction. A *henry* is defined as the inductance of a circuit in which a current change of 1 ampere per second causes a counter emf of 1 volt. Since the henry is defined in terms of practical units, the factor 10^{-9} must be used if the cemf is to be read in volts and the rate of change of the current in amperes per second.

Then

$$L = 4\pi N^2 \ \mu A/l \times 10^{-9} \text{ (henrys)}$$

Where: L = self-inductance of solenoid, in henrys
N = number of turns of coil
μ = permeability of core, in electromagnetic units
A = cross-sectional area of core, in sq cm
l = l mean length of core, in cm

This formula reveals the following important relationships: (1) The inductance of a coil is proportional to the square of the number of turns. (2) The inductance of a coil increases directly as the permeability of the material making up the core increases. (3) The inductance of a coil increases directly as the cross-sectional area of the core increases. (4) The inductance of a coil decreases as its length increases.

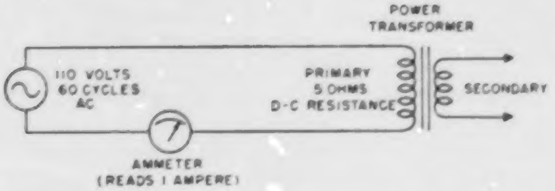

Fig. 1. Effect of cemf on current flow

Inductances in Series

The total inductance of a circuit containing more than one inductance connected in series is calculated in the same manner as that used for resistors in series. The total inductance is the sum of the separate inductances:

$$L_T = L_1 + L_2 + L_3 + \ldots + L_n$$

This formula, however, holds true only for circuits in which the inductances are shielded from each other, or so situated physically with relation to each other that no mutual inductance exists between them. If, on the other hand, two inductors are connected in series and so arranged that the flux lines link each other, the resultant total inductance must include the mutual inductance present. Then:

$$L_T = L_1 + L_2 \pm 2M$$

The plus-or-minus sign must be used in this general expression because the coils may be so placed that the induced voltages either aid or oppose each other, increasing or decreasing total inductance. For example, the formula for two inductors connected in series adding is:

$$L_T = L_1 + L_2 + 2M$$

The formula for connecting two inductances in series opposing is:

$$L_T = L_1 + L_2 - 2M$$

If the coils are so arranged that one can be rotated relative to the other, changing the coefficient of coupling K, the total inductance in the circuit can be varied. This is the principle of the variocoupler, or variometer, illustrated and explained in greater detail later.

Inductances in Parallel

The total inductance of a circuit containing more than one inductance connected in parallel is calculated in the same manner as that used for resistors in parallel. The total inductance is the reciprocal of the sum of the reciprocals of the individual inductances (provided the coils are shielded from each other, M equal to zero). Then:

$$L_T = \frac{1}{1/L_1 + 1/L_2 + \ldots + 1/L_n}$$

If the coils are of equal inductance, total inductance may be obtained immediately be dividing the inductance of one coil by the number of inductances in the circuit. Thus, four 1-henry inductors total one-fourth henry when connected in parallel.

For any two inductances, the simplified formula used with resistances may also be employed:

$$L_T = \frac{L_1 \times L_2}{L_1 + L_2}$$

As noted above, these formulas hold true only when the coils are shielded from each other. Any mutual inductance existing between inductances in parallel tends to reduce the total inductance. Thus, there can be no gain in total inductance and hence little practical use for unshielded inductances in parallel.

Inductive Reactance

In the discussion above, the opposition offered to a specific change of current by an inductance was measured at any given instant in terms of counter emf, the voltage bucking the applied voltage. In DC circuits, however, any opposition to current flow was termed resistance and measured in ohms. In AC circuits, therefore, it is convenient to measure inductive opposition in ohms rather than in counter emf or in volts. This type of AC opposition is called inductive reactance and is assigned the symbol X_L to distinguish it from a DC resistance.

Inductive reactance depends directly on the size of the inductance and on the rate of change of the current. In an AC circuit, the rate of change of the current is governed by the angular velocity of the applied voltage, and this velocity is measured in radians. Since each cycle is 2π radians, the angular velocity of any sine wave is equal to this factor multiplied by the frequency. Therefore, the inductive reactance of any circuit is equal to the inductance multiplied by the angular velocity, 2π, or

$$X_L = 2\pi fL$$

Where: XL = inductive reactance, in ohms
$2\pi = 6.28$
f = frequency, in cycles per second
L = inductance, in henrys

From this formula it may be seen that the higher the frequency, or the greater the inductance, the greater the inductive reactance. Figure 2A is a graph of X_L plotted against frequency, and figure 2B is a graph of X_L plotted against inductance. The graphs are similar and illustrate the inductive reactance increases directly, or linearly, with frequency and inductance. That is, the greater the frequency for any L, or the greater the inductance for any f, the greater the inductive reactance of the circuit.

At the high frequencies used in radio communications, even small amounts of inductance may offer very great inductive reactance. Figure 2C is a graph of current in an inductive circuit plotted against frequency. So, at high frequencies an inductance tends to act as an open circuit, since very little current flows in the circuit, and at low frequencies an inductance tends to act as a simple conductor—a short circuit—since high current flows. Thus, inductances designed for use at low frequencies are generally large iron-core inductances. They are measured in full units of henrys. Those used at high frequencies are generally small air-core inductances, which are measured in millihenrys (one-thousandth of a henry) or microhenrys (one-millionth of a henry).

For example, the opposition offered by a 20-henry inductance to a 110-volt, 60-cycle AC source may be found by using the formula for inductive reactance:

$$X_L = 2\pi fL$$

$$X_L = 6.28 \times 60 \times 20 = 7{,}536 \text{ ohms}$$

The current in this AC circuit is:

$$I = E/X_L = 110/7{,}536 = .014 \text{ amp}$$

If the frequency of this same circuit is increased to 400 cycles per second, the inductive reactance is increased:

$$X_L = 6.28 \times 400 \times 20 = 50{,}240 \text{ ohms}$$

Current falls to $I = 110/50{,}240 = .0021$ amp.

In a transmitter operating on 5 megacycles (5 million cycles per second), a small inductance of 2.5 millihenrys is used to keep substantially all alternating currents out of a certain part of the transmitter while at the same time allowing the passage of direct currents. This type of inductance is called a *choke* since inductive reactance at that frequency is quite high and effectively chokes off the alternating currents. Thus, $X_L = 2\pi fL = 6.28 \times (5 \times 10^6) \times (2.5 \times 10^{-3}) = 78{,}500$ ohms at 5 megacycles.

Voltage and Current across an Inductance: Phase Shift

Inductive reactance, as has been shown, not only limits the current flowing in an AC circuit but also tends to retard the building up and the falling off of current. In figure 3A, a sine wave of voltage is applied to a pure inductance. The current in the circuit also follows the form of the sine wave. However, it is necessary to determine precisely the delay in time between the application of the maximum voltage and the moment the current reaches maximum value, that is, the phase shift between the voltage and current.

Figure 3B illustrates the voltage and current sine curves for this circuit. Notice that the current lags the voltage by 90 degrees. For this reason, max-

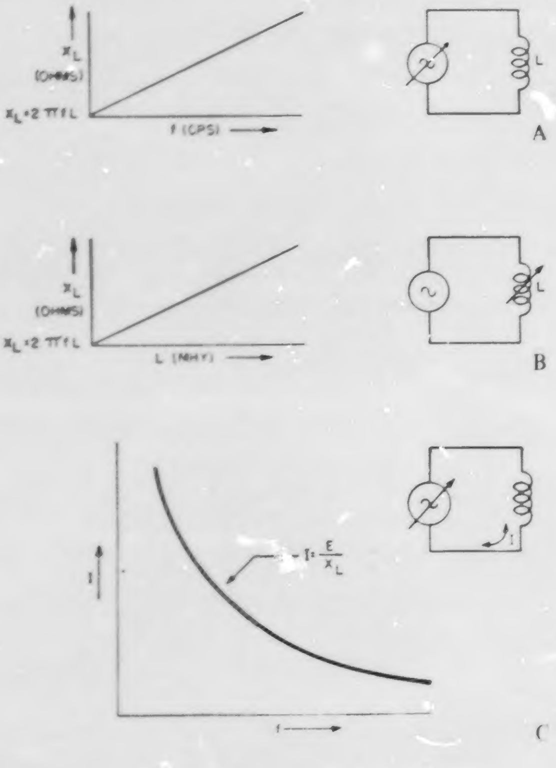

Fig. 2. Variation of inductive reactance

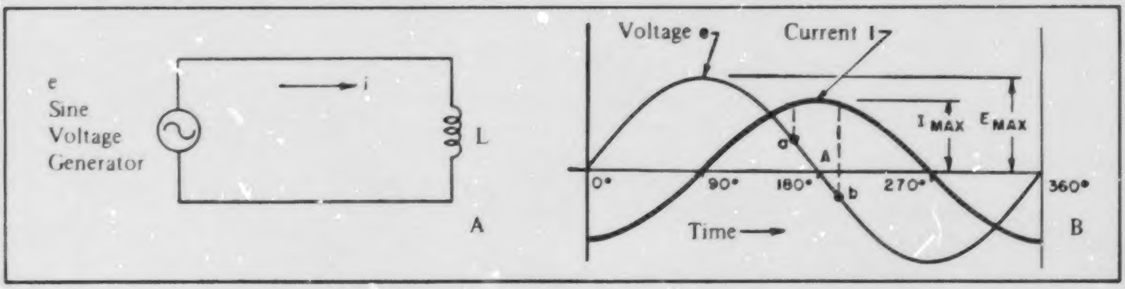
e
Sine
Voltage
Generator
i
L
A
Voltage e
Current I
I MAX
E MAX
a
A
b
0°
90°
180°
270°
360°
Time
B

Fig. 3. Current and voltage in an inductive AC circuit

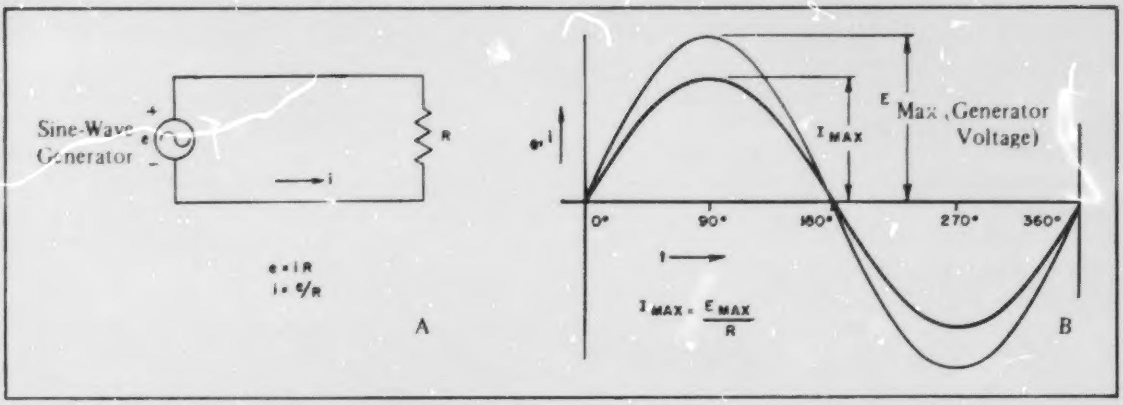
Sine-Wave
Generator
+
e
−
R
i
e = iR
i = e/R
A
e, i
E Max (Generator Voltage)
I MAX
0°
90°
180°
270°
360°
t
I MAX = E MAX / R
B

Fig. 4. Current and voltage in a resistive AC circuit

imum power cannot be used by such a circuit because power = I × E, and E is maximum when the current is zero. In other words, maximum power is used only when the current and voltage are in phase with one another. This condition can exist only in a pure resistive AC circuit. The waveforms for such a circuit are shown in figure 4B. The power factor of this circuit is 1.0, or unity (near 100 percent).

Exercise

1. Name the unit of measurement of inductance, and define it.
2. What is the formula for calculating the total inductance of two shielded inductors in series?
3. What is the formula for calculating the total inductance of three inductors in parallel?
4. State the formula for calculating the ohmic value of inductive reactance.
5. Why is maximum power used in a pure resistive AC circuit?

Objectives: After completing this assignment, you will be able to—

1. define capacitance and give the symbol used to identify it;
2. define capacitive reactance in AC circuits and give the symbol used to identify it;
3. write the formula for calculating the ohmic value of capacitive reactance;
4. tell the effect that capacitive reactance has on the sine wave voltage and current in an AC circuit; and
5. name three factors that affect the capacity of a capacitor.

H-2

Capacitance and Its Reactance to Alternating Current

Capacitors

A capacitor is formed when two metallic or conducting bodies are separated by an insulator. Practical capacitors are made by separating two or more metallic plates with a thin sheet of insulating material. In many cases these plates are made of thin metal foil, and the capacitor is designed to give a great plate area for its size, weight, and cost. Such a capacitor is shown in figure 1.

Figure 2A shows a parallel plate capacitor, which consists of two groups of thin copper plates separated by thin sheets of mica insulation. Figure 2B shows a variable capacitor, which consists of a set of parallel

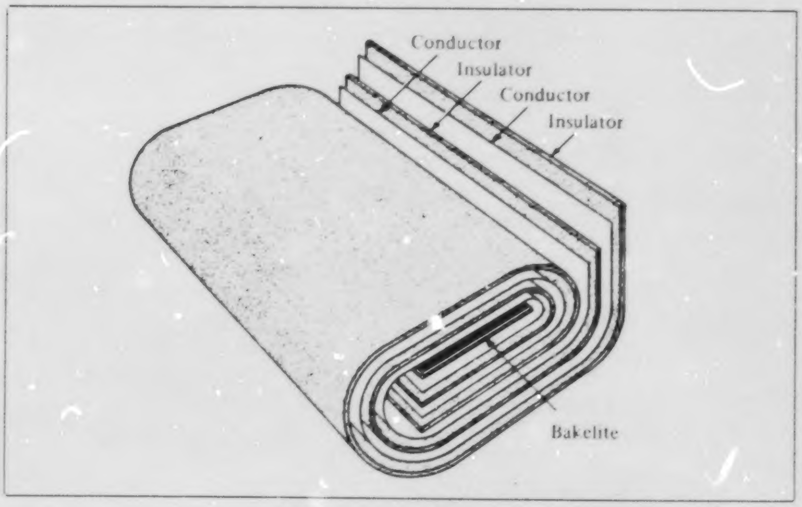

Fig. 1. Type of capacitor

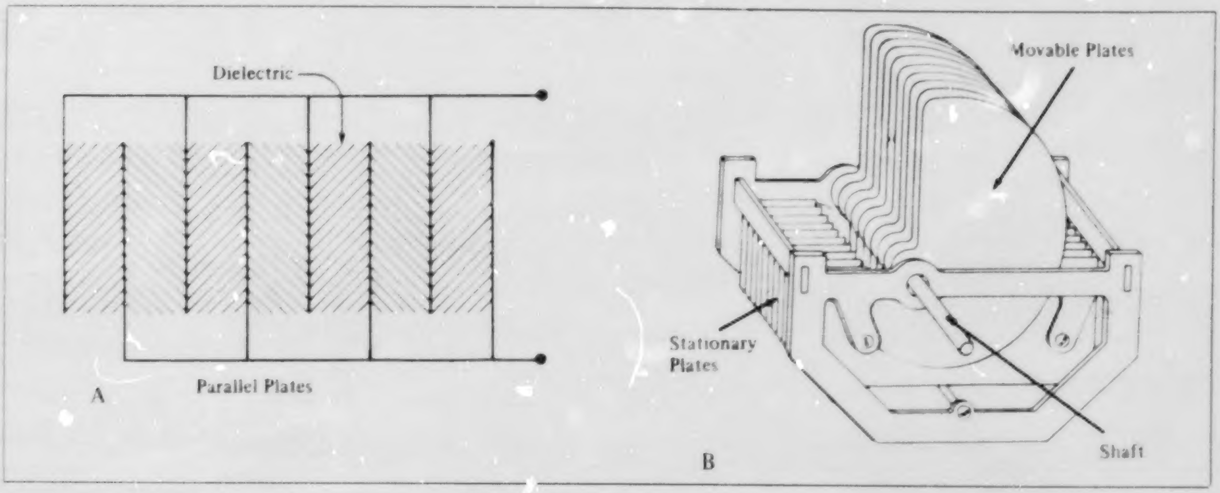

Fig. 2. Types of capacitors

plates mounted on a shaft and another set of fixed parallel plates. By turning the shaft, the movable set of plates meshes with the stationary set, but the two sets do not actually touch. This action varies the plate area, which varies the capacitance of the capacitor. The air between the plates serves as the insulator.

The insulating material between the plates of a capacitor has a special name, the *dielectric*. Materials used as dielectrics are wax paper, mica, air, gases, oils, and chemicals. Capacitors are classified according to their dielectric. For example, a capacitor with a mica dielectric is called an electrolytic capacitor. One type of capacitor is housed in a metal container, filled with oil, and sealed. Although the dielectric is paper, this type is called an oil-filled capacitor.

Figure 3A shows a capacitor made up of two metal plates separated by an insulator, or dielectric. Before the battery is applied, each plate is electrically neutral. That is, each plate has enough negative charges to exactly balance the positive charges of the metal. In other words, the plates are uncharged.

At the instant the switch is closed, as in figure 3B, electrons are forced into plate A from the negative terminal of the battery. At the same time, electrons are pulled from plate B to the positive terminal of the battery. Now plate A is charged negatively, and plate B is charged positively. The potential difference across the plates of the capacitor will rise from zero at the instant of connection to the full voltage of the battery, but no more than this. When the switch is opened, a charge is trapped in the capacitor (fig. 3C). The charge will remain trapped for some time, depending on the quality of the dielectric.

A large capacitor may be charged to high voltage and contain enough electrical energy to kill or injure a person. Care should be used when handling capacitors even though they are completely removed from the circuit. Make sure that they are discharged before they are handled.

Figure 3D shows a charged capacitor with the battery switch open. A shorting switch is provided in the circuit to discharge the capacitor. At the instant the shorting switch is closed, electrons rush out of the negatively charged plate through the circuit completed by the switch and onto the positively charged plate. This current flows until the positive and negative charges on both plates are balanced. The capacitor is then discharged and will remain discharged until the battery is connected to it again.

The following points should be remembered when direct current is applied to a capacitor:

1. When a capacitor is connected to a battery, a current will flow from and

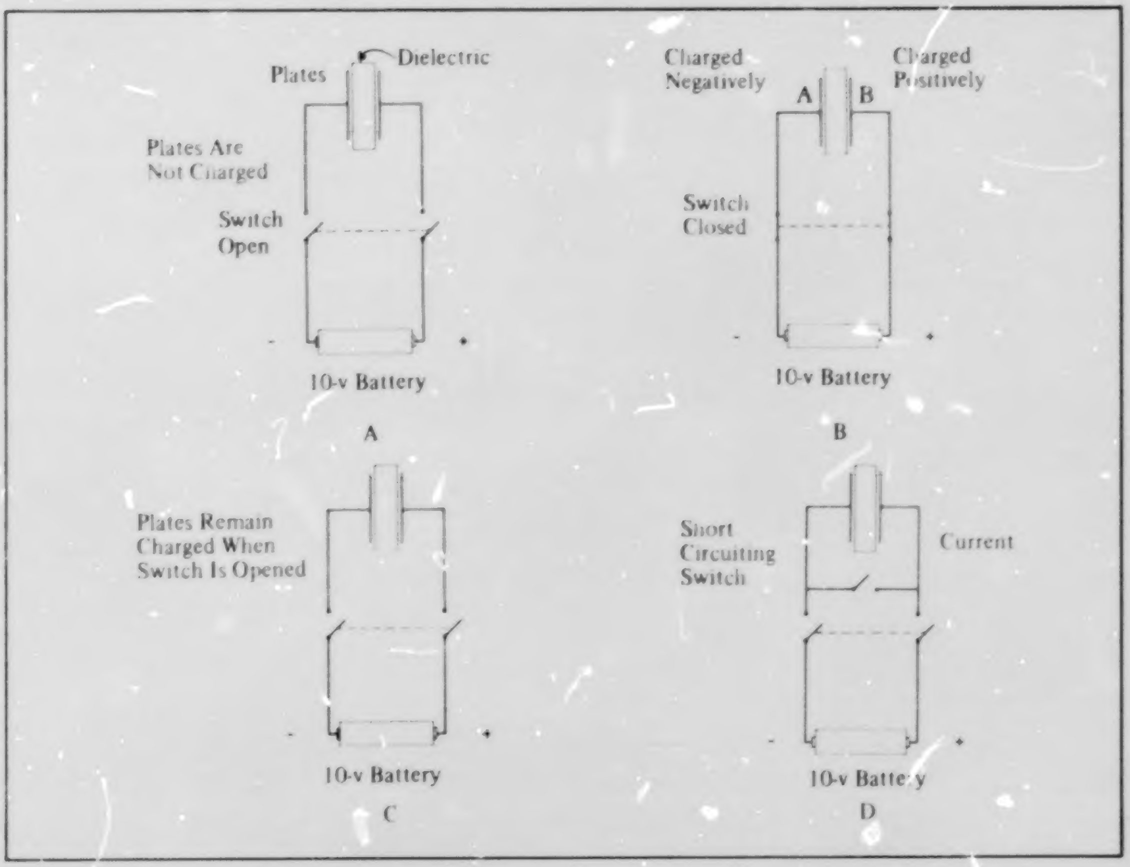

Fig. 3. *Charging and discharging action of a capacitor*

to the battery to charge the capacitor.

2. Once the capacitor is charged to the same voltage as the battery, no more current will flow from the battery no matter how long the capacitor is left connected to the battery.

3. A capacitor will charge to the same voltage as the battery that is used to charge it.

4. Some small amount of time is required to charge a capacitor or to discharge it. (Nothing happens instantly.)

5. At the instant an uncharged capacitor is connected to a battery, the current that charges the capacitor will be at a maximum. As the capacitor continues to charge, the current becomes less and less. This is because the voltage (counter voltage) that builds up across the plates of the capacitor opposes the voltage of the battery. When these two voltages become equal, there is no potential difference (no voltage) to cause the current to continue to flow.

6. At the instant the capacitor is discharged, the current will again be at a maximum. This discharge current will become less and less until the capacitor is completely discharged.

7. The trapped charge in a disconnected capacitor can cause serious injury. Before handling a capacitor, carefully discharge it by shorting across the terminals with a screwdriver that has a well-insulated handle.

Capacity

Just as resistors are rated in terms of their ability to oppose the flow of current, capacitors are rated according to their ability to hold a charge. This ability is called *capacity* or *capacitance*. Several factors that affect the capacity of a capacitor will be considered now.

Area of Plates. The capacity of a capacitor varies directly with the area of the plates used. A capacitor with low capacity is one whose plates have a small area, and a capacitor with high capacity is one whose plates have a large area. In the case of a capacitor with only two plates, only that area of the plates where the plates face each other is considered. In order to have a large plate area, and thus high capacity, capacitors are made of very thin metal foil. Rolling these alternate layers of metal foil and paper dielectric into a roll conserves space and makes a smaller package (fig. 4).

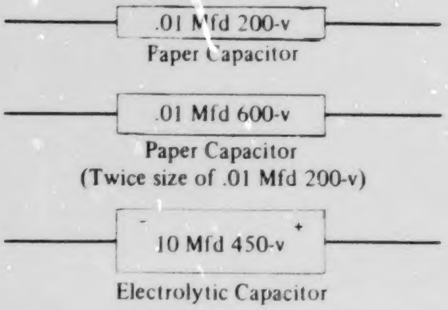

Fig. 4. Comparison of physical size of capacitors

Distance between Plates. As the distance between the plates of a capacitor increases, the capacity decreases. The closer the plates are together, the higher the capacity. The thickness of the dielectric between the plates determines the distance between the plates. With a given plate area, the capacity can be increased by using a thinner dielectric because this decreases the distance between the plates. There is a limiting factor as to how thin the dielectric can be made, though, and that is the amount of voltage expected to be applied to the capacitor. If the dielectric is too thin for a given voltage, this voltage will rupture the dielectric and short out the capacitor. Once a hole is burned in the dielectric, the plates are effectively touching, and the capacitor is no longer useful.

Dielectric Materials. The kind of dielectric used in a capacitor will also affect the capacity of a capacitor. If a capacitor that uses air for the dielectric is immersed in a nonconductive liquid, such as oil, or if solid insulation is inserted between the plates, the capacity of the capacitor will increase. Air is used as a standard, and all other materials are rated in reference to air. Air has a dielectric constant of 1. Mica has a dielectric contant of 6. This means that a capacitor with a given plate area and given spacing between the plates would have six times as much capacity if the dielectric were mica rather than air. The dielectric constants of several materials are given in parentheses: air (1), glass (9), mica (6), paraffin paper (3.5), ethyl alcohol (28.4), average oil (3), and pure water (81).

The dielectric constant of a material must not be confused with its dielectric strength. The *dielectric strength* of a material is the voltage per mil (one-thousandth of an inch) required to break down the material. The dielectric strength of a material is a measure of its insulating ability. The dielectric constant is a measure of the material's capacitive effect. The dielectric strengths of several materials, in volts per mil, are as follows: air (76), Bakelite (150 to 500), glass (760 to 3,800), paper (250 to 650), mica (760 to 5,000), oil (100 to 500), and pure water (380).

Unit of Measurement of Capacity

The *farad* is the basic unit used to measure capacity or capacitance. When a charge of one volt per second across the capacitor produces a charge or discharge current of one ampere, the capacitor is said to have a capacitance of one farad. The farad is too large a unit for practical purposes, so the microfarad (one-millionth or 10^{-6} farad) and the picofarad (micro-microfarad or 10^{-12} farad) are generally used. The picofarad is used with very small capacitors that are commonly used in electronics.

The equation for determining the capacity of a capacitor is:

$$C = \frac{2.25KA}{d \times 10^7}$$

Where: C = capacity, in microfarads
K = dielectric constant of dielectric
A = area of plates, in square inches
d = distance between plates, in inches
2.25 and 10^7 = constants

Example: What is the capacity of a capacitor made of two metal plates, 10 inches by 10 inches, that are separated by paraffin paper that is .001 inch thick with a dielectric constant of 3?

$$\begin{aligned} C &= 2.25KA/d \times 10^7 \\ &= 2.25 \times 3 \times 10 \times 10/.001 \times 10{,}000{,}000 \\ &= 6.75 \times 100/10{,}000 \\ &= 675/10{,}000 \\ &= .0675 \text{ microfarad} \end{aligned}$$

Capacitors are rated not only in terms of their capacity in microfarads, but also in terms of the maximum voltage that may safely be applied to them. This rating is called the maximum ***working voltage*** rating. Capacitors are tested for short periods of time at higher voltages than the working voltage, and this voltage is called the test voltage. The test voltage is not usually specified for the capacitor, but the working voltage is.

Type and Thickness of Dielectric

The voltage rating of a capacitor is determined by the dielectric strength of the dielectric (breakdown voltage per mil thickness). If the voltage rating of a capacitor is low, the dielectric may be thin and the area of the plates may be smaller to provide a capacitor of a given capacity in microfarads. To increase the voltage rating of a capacitor, the thickness of the dielectric must be increased, which means that the area of the plates must be increased. Physically, a .01 microfarad (Mfd) capacitor rated at 200 volts is about half the size of a capacitor rated at the same capacity but with a 600-volt rating. This is because the 600-volt capacitor requires a thicker dielectric and larger plate area. Both the size and cost of a capacitor go up as the voltage rating is increased (see fig. 4). Generally, this is true of other electrical components.

Electrolytic capacitors use an oxide film for the dielectric, and this film is very thin. Thus, electrolytic capacitors are very small compared to other types of the same capacity and voltage rating.

Polarized and Nonpolarized Electrolytic Capacitors

Polarized electolytic capacitors may be used in DC circuits only. Other types of capacitors, such as paper and mica, may be used in either AC or DC circuits. Also, electrolytic capacitors must have a specified terminal connected to the positive polarity and the other terminal connected to the negative polarity. These terminals of a polarized electrolytic capacitor are plainly marked plus (+) and minus (−). If the plus terminal of a polarized electrolytic capacitor is connected to the negative polarity of a circuit, it will pass current and become shorted. If it is connected correctly, it will only store up a charge. The main advantage of an electrolytic capacitor over other types is its high capacity in a small package (see fig. 4).

A capacitor of large capacity and small physical size was needed for the starting circuit of small induction motors. Although a polarized electrolytic capacitor could meet the capacity and size required, it could not be used because alternating current is used in these motors. A special nonpolarized electrolytic capacitor was designed for this purpose. Basically, this capacitor consists of two polarized capacitors connected in series, with like polarities at the junction point (see fig. 5). With this novel arrangement, one of the capacitors stores a charge while the other capacitor becomes shorted. Then, during the other half of the AC cycle, the former becomes shorted while the latter becomes charged. Capacitors of this type cannot be left in the circuit for long periods of time. On nonpolarized capacitors, the terminals are not marked plus and minus, but the capacity and voltage are given.

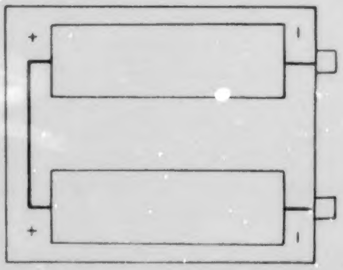

Fig. 5. Nonpolarized electrolytic capacitor

Capacitors in Series and in Parallel

The total capacitance of a circuit containing more than one capacitor connected in series is calculated in the same manner as that for resistors in parallel. The total capacitance is the reciprocal of the sum of the reciprocal of the individual capacitors. Thus:

$$C_T = \frac{1}{1/C_1 + 1/C_2 + \ldots + 1/C_n}$$

This formula shows that other generalizations true of resistors in parallel may be applied to capacitors in series. The total capacitance is less than the capacity of the smallest element. If capacitors are of equal value, the total capacitance may be obtained immediately by dividing the capacity of one by the number of capacitors. For any two capacitors, the simplified formula may be used:

$$C_T = \frac{C_1 \times C_2}{C_1 + C_2}$$

That two capacitors in series give a total capacity less than one capacitor is evident from the diagram in figure 6A. Note that the addition of another capacitor in effect widens the distance between the plates while the area of the plates remains the same. Thus, total capacity is less since C = A/d. On the other hand, the total capacitance of a circuit containing capacitors connected in parallel is calculated by the simple addition of the individual capacities, as with resistance in series. Thus:

$$C_T = C_1 + C_2 + C_3 \ldots + C_n$$

Figure 6B shows two capacitors connected in parallel. The addition of the second capacitor in effect increases the area of the plates without changing the distance between them. Thus, by the formula above, the total capacity increases and is always greater than the larger capacity. Two examples follow:

1. A technician needs a .01-Mfd capacitor to use in a circuit where 1,000 volts are applied to the capacitor. If he does not have a capacitor with this rating, he can use two .02-Mfd capacitors rated at 600 volts. When placed in series, they become the equivalent of a single capacitor rated at .01 Mfd and 1,200 volts. The higher voltage rating simply provides an extra safety margin.

2. If a technician needs a 50-Mfd capacitor rated at 450 volts, she may connect two 25-Mfd capacitors that have a 450-volt rating in parallel. Then she has the equivalent of a single 50-Mfd capacitor rated at 450 volts.

Current through Capacitors

If a light bulb of proper size is placed in series with the capacitor and a transformer secondary, it will glow as a result of the charge-discharge currents passing through the bulb. The results are almost the same as if the current from the transformer did actually pass through the capacitor from plate to plate, which it cannot do because of the dielectric between the plates. For calculation purposes, capacitors are treated as though they conduct alternating current. Capacitors of large capacity are considered good conductors of alternating current, and capacitors of low capacity are considered poor conductors. Capacitors offer opposition to the passage of alternating current much as a resistor offers opposition to the passage of current.

Capacitive Reactance

When alternating current is applied to a capacitor, the capacitor must charge in one direction, discharge, then charge in the other direction, and discharge, all in one cycle or one-sixtieth of a second. In other words, a capacitor is in a constant state of charge and discharge when it is in an AC circuit. The reactance of the capacitor not only increases the current flowing in an AC circuit but tends to retard the building up and falling off of the voltage. Since the reaction of an inductance to alternating current is measured in ohms, inductive reactance (X_L) finds its counterpart (opposite reaction) in capacitive reactance, which is given the symbol X_C and measured in ohms. The formula for finding capacitive reactance is shown:

$$X_C = \frac{1}{2\pi fC}$$

Where: $2\pi = 6.28$
f = frequency, in cycles per second
C = capacitance, in farads
X_C = capacitive reactance, in ohms

This formula shows that the higher the frequency, or the greater the capacitance, the less the capacitive reactance. Figure 7A is a graph of X_C plotted against frequency, and figure 7B is a graph of X_C plotted against capacitance. The graphs are similar and show that capacitive reactance decreases nonlinearly with the frequency for any C. Or, the greater the capacitance for any f, the less the capacitive reactance of the circuit.

At the very high frequencies used in radio communications, even small stray amounts of capacitance offer a path of such low reactance to the signal voltage that often a desired signal is short-circuited. At the other extreme, the separate DC circuits are effectively isolated from each other by either small or large capacitors since either offers a path of maximum reactance to direct current. Figure 7C, a graph of current in a capacitive circuit plotted against frequency, shows these relationships.

At low frequencies a capacitor tends to act as an open circuit, since current is very low, and at high frequencies a capacitor tends to act as a simple conductor, or short circuit. Thus, capacitors designed for use at low frequencies are generally large capacitors, measured in full units of microfarads (one-millionth of a farad). Those used at high frequencies are generally small capacitors, measured in micromicrofarads (one-millionth of a microfarad).

For example, the opposition offered by a 2-microfarad capacitor to a 110-volt, 60-cycle AC source may be found by using the formula for capacitive reactance:

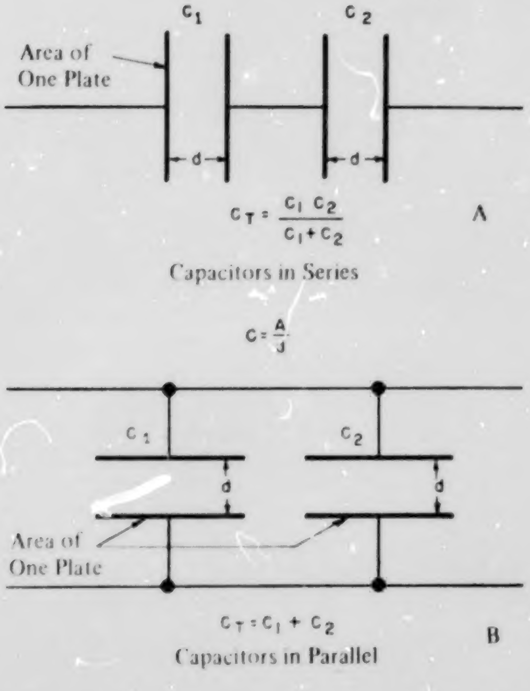

Fig. 6. Capacitors in series and in parallel

$$X_C = 1/2\pi fC$$
$$= 1/(6.28 \times 60 \times 2 \times 10^{-6})$$
$$= 10^6/(6.28 \times 60 \times 2)$$
$$= 1{,}333 \text{ ohms}$$

The current in this AC circuit is:

$$I = E/X_C = 110/1{,}333$$
$$= .0825 \text{ amp}$$

If the frequency of this same circuit were increased to 1,000 cycles per second, the capacitive reactance is decreased:

$$X_C = 1/(6.28 \times 1{,}000 \times 2 \times 10^{-6})$$
$$= 79.7 \text{ ohms}$$

Current increases to:

$$I = 110/79.7 = 1.38 \text{ amp}$$

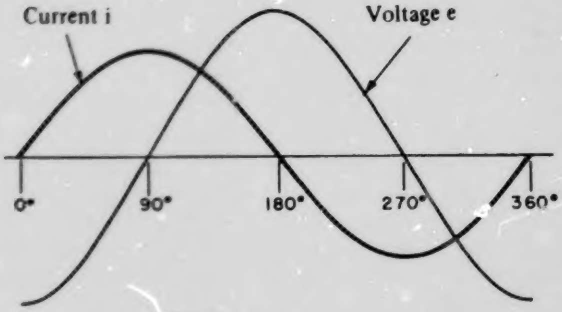

Fig. 8. Sine wave forms

In a transmitter operating on 7 megacycles (7 million cycles per second), a small capacitance of 250 micromicrofarads (.00025 microfarads) is used to block direct currents out of a certain part of the transmitter while at the same time allowing the passage of the AC signal. Such a capacitor is called a DC blocking or AC coupling capacitor since it offers infinite resistance to the DC and is a conducting path to the AC signal. Thus:

$$X_C = 1/2\pi fC$$
$$= \frac{1}{6.28 \times 7 \times 10^6 \times 250 \times 10^{-12}}$$
$$= 10^6/(6.28 \times 7 \times 250)$$
$$= 10^4/(6.28 \times 7 \times 2.5)$$
$$= 91.0 \text{ ohms at 7 megacycles}$$

Figure 8 shows the sine wave forms for the applied voltage and the current in a pure capacitive circuit. Notice that the current leads the voltage by 90 degrees. This effect is exactly opposite to that of a pure inductive circuit.

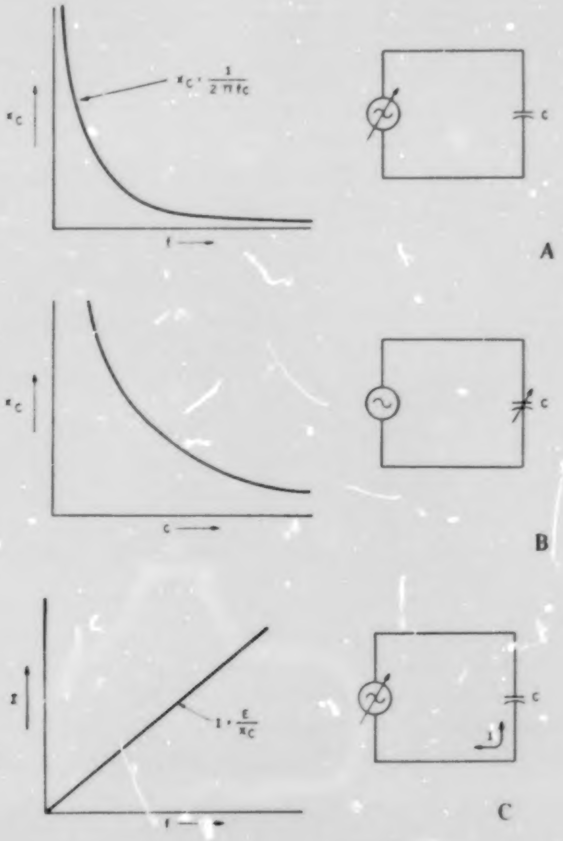

Fig. 7. Variation of capacitive reactance

Some Applications of Capacitors

Capacitors are sometimes placed across the contact points of relays (magnetic switches). An electric arc is pulled when current-carrying contacts are opened. This arc burns and pits the contacts and shortens the life of the points. Arcs nearly always set up high-frequency currents that can damage the insulation of parts in the circuit and cause radio and television interference. They can also upset the performance of delicate electronic circuits. The magnitude of the arc is reduced by the action of the capacitor.

Carbon brushes are used to make contact to motor or generator commutators. They are constantly making and breaking the circuit to the coils in the rotor, so arcing and sparking may occur. The addition of capacitors across the brushes tends to reduce the arcing and prolongs the life of the brushes and commutator.

Time-Delay Circuits

If a capacitor is charged through a resistor (fig. 9), some time is required for the capacitor's voltage to rise from zero (the uncharged state) to the full voltage of the charging source. The amount of time required to charge the capacitor under these circumstances depends on the value of the resistor in ohms and the capacitor in microfarads. A simple equation for determining the time required to charge the capacitor to

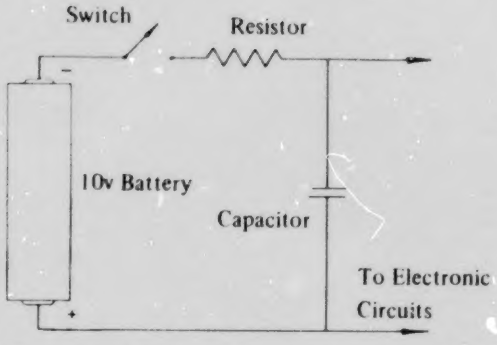

Fig. 9. Resistance-capacitance time-delay circuit

63 percent of the voltage applied to it, or the time required for a capacitor to discharge to 37 percent of its fully charged voltage, is as follows:

R × C = T

Where: R = resistance, in ohms
C = capacity, in microfarads
T = time, measured in microseconds to charge 63 percent

Note: one million microseconds equal one second.

For example, if 10 volts are applied to a circuit consisting of a 1,000,000-ohm resistor in series with a 1-Mfd capacitor, how long does it take the capacitor to charge to 6.3 volts (63 percent of 10 volts)? Substituting in the equation, we have 1,000,000 × 1 = 1,000,000 microseconds.

Capacitors Used in Rectifier Circuits

Rectifier circuits are used to change alternating current into direct current. The action of the rectifying circuit produces a pulsating direct current. If, however, a smooth direct current (pure direct current) is desired, a large capacitor, called a "filter capacitor" in this case, is used. Pure direct current is not necessary for battery charging and corrosion applications, as pulsating direct current will work as well. However, since the direct current required for electronic apparatus must be pure, filter capacitors are required in these circuits.

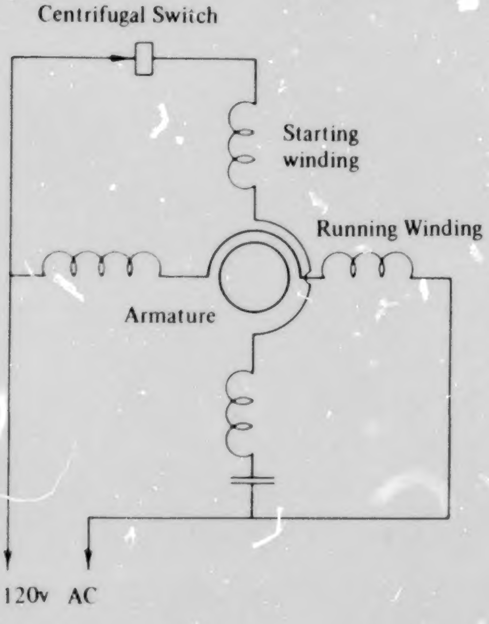

Fig. 10. Capacitor-start induction motor

Starting Circuits in Induction Motors

Nonpolarized electrolytic capacitors are very commonly used in the starting circuit of fractional-horsepower, single-phase induction motors. Induction motors work on the principle of rotating magnetic fields. The single-phase induction motor has no starting torque (tendency to turn) unless a special starting circuit is added. One type of starting circuit uses a capacitor, and a motor equipped with this type is called a capacitor-start motor (fig. 10). This starting circuit consists of coils mounted in the motor stator, a switch operated by centrifugal force, and the starting capacitor. The coils are called the starting winding and are left in the circuit only until the motor reaches 70 percent of its normal starting speed. At this point, the starting circuit is opened by the centrifugal switch. The main coils of the motor, which are left in the circuit at all times, are called the running winding. The capacitor is used in the circuit because of its ability to cause a 90-degree shift in the current that passes through it.

Power Factor Correction

Motors, like capacitors, cause the current through the motor to become out of phase (out of step) with the AC voltage applied to the motor. A motor causes the current to lag behind the applied voltage by amounts up to 90 degrees, or one-quarter of a cycle. This lagging phase shift results in power line losses because some current is made to flow through the motor windings that is not converted into useful horsepower. Since capacitors cause a leading phase shift, the line current can be brought back in phase with voltage by connecting a capacitor across the line supplying the motor. This greatly reduces line losses. The term *power factor* expresses the degree to which current and voltage are out of phase. If the voltage and current are in phase, the power factor is 1, the best power factor. If the voltage and current are 90 degrees out of phase, the power factor is 0, the worse possible power factor. Power factors between 0 and 1 are given in parentheses for the angle that current and voltage are out of phase: 10 degrees (.98), 20 degrees (.93), 30 degrees (.86), 45 degrees (.70), 60 degrees (.50), 75 degrees (.25), 80 degrees (.17).

Exercise

1. What is the unit used for capacity measurement, and what is its symbol?
2. What is the practical unit used for capacity measurement?
3. What is the insulation between the plates of a capacitor called?
4. What are three factors that affect the capacity of a capacitor?
5. What is the breakdown voltage of a dielectric called?
6. Define *farad*.
7. Give the formula for finding the total capacity of two capacitors in parallel.
8. Why is it important to discharge large capacitors by shorting their terminals with a screwdriver blade before handling?
9. What is capacitive reactance, and what is its symbol?
10. Give the formula for calculating the ohmic value of capacitive reactance.
11. What effect does capacitive reactance have on the sine wave voltage and current in an AC circuit?

H-3

Alternating-Current Principles

Objectives: After completing this assignment, you will be able to—

1. explain impedance in AC circuits, and give the symbol used to present it;
2. name the unit of measurement of impedance;
3. explain why the total values of the circuit must be calculated by combining vectorially the in-phase values with the out-of-phase values; and
4. discuss the power factor in AC circuits.

Impedance

The separate or combined effects of inductance and capacitance in an alternating current affect the total resistance of the circuit. Thus, in an AC circuit, it is not only necessary to consider the pure resistance of wires, motors, and other resistances, but also the retarding effects of coils and the capacitive effect of condensers. These effects, measured in the same unit as resistance (in ohms), are referred to as inductive and capacitive reactance. Since the effects of inductive reactance and capacitive reactance on current are opposite, they tend to neutralize each other. Their effect on the circuit can be calculated, for practical purposes, by taking the arithmetical difference between the two.

The *total reactance* of the circuit is arrived at by subtracting the smaller reactance from the larger. That is, you subtract capacitance from inductance, or inductance from capacitance. This total reactance, when combined with the resistance of a circuit, will then give the total opposition of a circuit to the passage of an alternating current. This is called *impedance*, which is measured in ohms and represented by the symbol Z.

In other words, the Ohm's law formula can still be used to calculate AC values in pure resistive circuits ($E = IR$), but it must be modified by substituting impedance (Z) for resistance when inductors and capacitors appear in the circuit ($E = IZ$). The big problem in AC circuits is to find the value of Z. Z contains the resistive element R and the reactive element X, which cannot be added arithmetically because they are 90 degrees out of phase with one another. However, the values of out-of-phase elements in AC circuits can be solved by arranging vectors that represent the elements in the form of a right triangle. The sides (vectors) of a right triangle must all represent the same units of measurement (ohms, amperes, or volts).

The following is a review of the definitions and rules pertaining to the functions of the right triangle. An *angle* is a figure formed when two lines meet at a point. A *right angle* is formed by the rotation through one-fourth of a circle. Since a complete circle contains 360 degrees, a right angle contains one-fourth of 360, or 90 degrees. An *acute angle* contains less than 90 degrees. The sum of the two acute angles in a right triangle is 90 degrees. Therefore, the sum of all the angles in a right triangle is 180 degrees. If two angles are known, it is a simple matter to find the third angle by subtracting the sum of the two known angles from 180 degrees.

When a right triangle is in its standard position, as in figure 1A, the horizontal side is called the *base* (b). The vertical side is called the *altitude* (a). The longest side is called the *hypotenuse* (c) and is opposite the largest angle (90 degrees).

Some writers identify the three angles of a triangle by capitalizing the letter of the side opposite each angle, while others use some letter of the Greek alphabet. The four Greek letters most commonly used to designate angles are alpha (α) beta (β), phi (ϕ), and theta (θ). They have no significance other than to name a specific angle without having to describe the

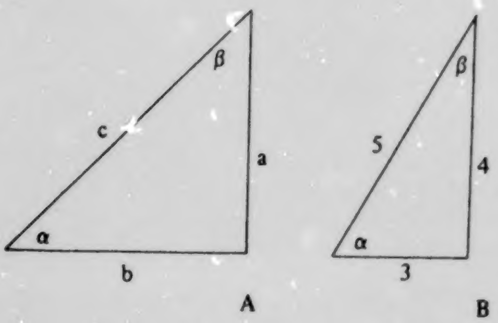

Fig. 1. Right triangles

angle's location. For example, "angle α" designates the angle formed by the junction of sides b and c. Designating an angle by its Greek letter reduces the possibility of confusing that angle with a particular side of the triangle in question.

Several useful facts relating to the right triangle are shown in figure 1A. A certain relationship exists between the three sides of any right triangle, and it is used often in problems involving vector forces. This relationship states that "the square of the hypotenuse of a right triangle is equal to the sum of the squares of the other two sides." This law stated as an equation relating to the triangle in figure 1A would read $c^2 = a^2 + b^2$, also $a^2 = c^2 - b^2$ and $b^2 = c^2 - a^2$. This law is usually applied to find the value of one side of a right triangle when the values of the other two sides are known. Using the square roots of both sides of the three equations listed above, this would normally be written as follows:

$$c = \sqrt{a^2 + b^2}$$

$$a = \sqrt{c^2 - b^2}$$

$$b = \sqrt{c^2 - a^2}$$

By assigning definite values to the three sides as shown in figure 1B, the validity of the statements above can be checked. Where a = 4, b = 3, c = 5, then the following equality is true:

$5^2 = 4^2 + 3^2$ or $25 = 16 + 9$

Since the sum of 16 and 9 is 25, the equality is maintained. By the same process $4^2 = 5^2 - 3^2$, and $3^2 = 5^2 - 4^2$. Carrying the process one step further, it is easy to see that the following equations are also true.

$$5 = \sqrt{4^2 + 3^2},$$

$$4 = \sqrt{5^2 - 3^2}, \text{ and}$$

$$3 = \sqrt{5^2 - 4^2}$$

For alternating-current calculations, let the base (b) of the triangle represent the in-phase elements and the altitude (a) represent the out-of-phase reactive elements. The hypotenuse (c) is the result of the two forces (a and b) acting on one another. The following points should be remembered about series AC circuits.

1. In a series circuit, the current is the same through all parts. Therefore, the vectorial sum of the resistance and reactance is the impedance. Reactance will be either inductive or capacitive (except at resonance when $X_L = X_C$).

2. The current in a series L-C-R circuit either leads or lags the applied voltage depending on whether X_C is greater than or less than X_L.

3. A capacitive voltage drop (E_C) in a series circuit always subtracts directly (arithmetically) from inductive voltage drop (E_L).

4. The voltage across a single reactive element can have a greater effective value than that of the applied voltage.

The various relationships noted above may now be generalized, and the current, impedance, voltage drops, and phase angle of any series L-C-R circuit calculated. Figure 2A is a diagram of a series circuit with an induc-

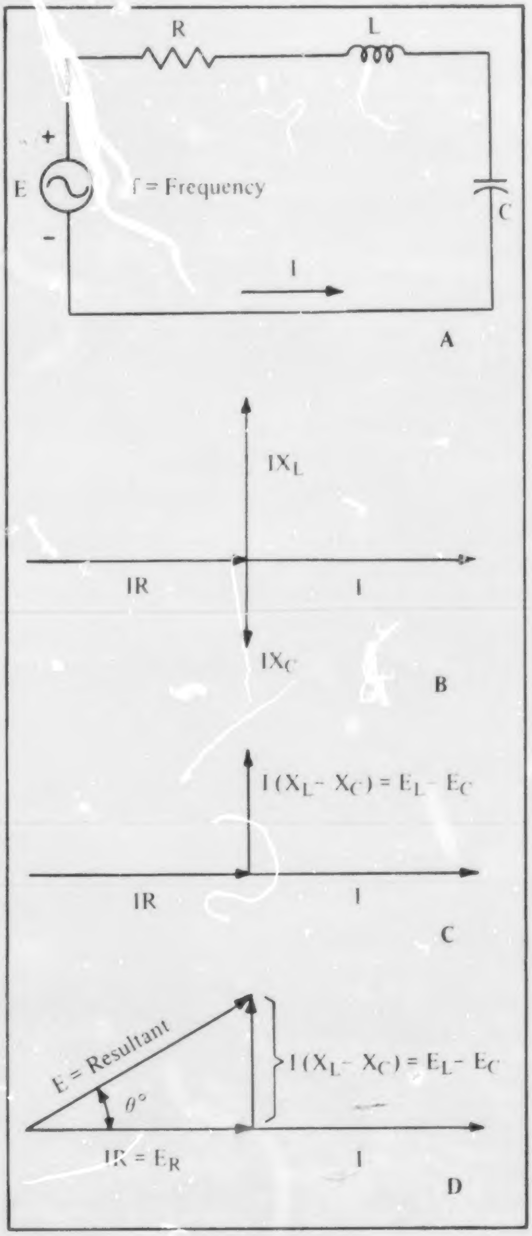

Fig. 2. L-C-R circuit: phase relation

tance L, a capacitance C, and a resistance R. This circuit is connected to an AC voltage source of magnitude E and frequency f. Figure 2B shows the initial vector diagram. The voltage drop across the resistance, IR, is drawn above the zero axis, and the voltage drop across the capacitance is drawn below the axis. Figure 2C shows the resultant vectors, and the voltage triangle (with base E_R and vertical side $E_L - E_C$) is shown in figure 2D. The resultant voltage E, equal to the applied voltage, is the hypotenuse of the right triangle. Then:

$$E^2 = I^2R^2 + I^2 (X_L - X_C)^2$$

$$E^2 = I^2 [R^2 + (X_L - X_C)^2]$$

The square root

$$E = I \sqrt{R^2 + (X_L - X_C)^2}$$

and transposing

$$I = \frac{E}{\sqrt{R^2 + (X_L - X_C)^2}}$$

Also, since in any AC circuit I is equal to E/Z, then Z, the total impedance of an L-C-R circuit, is equal to the square root of the square of the resistance plus the square of the differences of the reactances present:

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

From the voltage triangle, it is seen that the current lags the applied voltage by the angle θ. These results may be written in another form. Since X_L is equal to $2\pi fL$, and X_C to $1/2\pi fC$, then:

$$Z = \sqrt{R^2 + (2\pi fL - 1/2\pi fC)^2}$$

In all of the preceding calculations the values of I and E are the effective, or rms, values of current and voltage.

From the general formulas given above, then, if the inductive reactance X_L is greater than the capacitive reactance X_C, the inductive voltage drop is greater than the capacitive voltage drop, and their sum is inductive. That is, the voltage leads the current by 90 degrees. Finally, if the inductive reactance equals the capacitive reactance, the sum is zero, and a very interesting phenomenon called resonance occurs. In this case, the inductive and capacitive voltage drops are equal in magnitude and 180 degrees out of phase. Thus, their vector sum is zero.

The voltage in a parallel circuit is the same across all parallel components. At any nonresonant point (X_L not equal to X_C), the currents through L and C, of a parallel L-C-R circuit, will be unequal and 180 degrees out of phase with one another. Therefore, the resultant current will be either inductive or capacitive, depending on the branch offering the least opposition to the applied voltage. The generator looking into this circuit would see either a capacitance or an inductance in parallel with the resistance. The resultant line current is the vector sum of the reactive current and the resistive current. Although the reactive current is 90 degrees out of phase with the resistive current, the resultant line current is at some angle less than 90 degrees. The formula for finding total line current is as follows:

$$I = \sqrt{I_R^2 + (I_L - I_C)^2}$$

Now, the impedance (Z) can be determined by Ohm's law:

$$Z = E/I$$

The formula for finding the impedance without first finding the current is almost the same as the one for finding resistance by the conductance method in parallel DC circuits in which:

$$R = \frac{1}{1/R_1 + 1/R_2 + 1/R_3}$$

The formula for finding impedance (Z) in a parallel circuit containing one inductive branch, one capacitive branch, and one resistive branch is:

$$Z = \frac{1}{\sqrt{(1/R)^2 + (1/X_L - 1/X_C)^2}}$$

There are some problems relating to right triangles where the numerical value of only one of the sides is known. It is obvious that under these circumstances the "sum of the squares" method cannot be used to supply the missing information. However, if in addition to the numerical value of one of the sides the value of one of the acute angles is known, the numerical values of the remaining two sides can be found, by using one of the trigonometric ratios of the acute angle under consideration. There are six trigonometric ratios for an acute angle, but only three are needed for this purpose. The sine, cosine, and tangent are the ratios most frequently used in practical work. The numerical value of any one of the ratios depends only on the magnitude of the angle. Consider the right triangle shown in figure 3. Notice that side a is opposite the acute angle θ and that side b is adjacent (to the right) to angle θ.

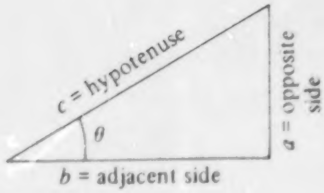

Fig. 3. Right triangle

The sine ratio, written

$$\sin\theta = \frac{\text{opposite side}}{\text{hypotenuse}} = a/c$$

The cosine ratio, written

$$\cos\theta = \frac{\text{adjacent side}}{\text{hypotenuse}} = b/c$$

The tangent ratio, written

$$\tan\theta = \frac{\text{opposite side}}{\text{adjacent side}} = a/b$$

It can be seen that these ratios are nothing more than simple equations. If the values of the two sides are known, the indicated division (a/c, b/c, or a/b) will give a numerical value of the angle under consideration. This value can be read in terms of degrees by locating the nearest number to the value of either the sine, cosine, or tangent column of a prepared table of trigonometric ratios, or functions (see table 1). This same table can be used to find the numerical value of an angle given in degrees. For example, find 30° in the column of angles in table 1. Notice that sin 30° = 0.5000, cos 30° = 0.8660, and tan 30° = 0.5774.

The value of any unknown side of a triangle can be determined if the value of one side and the acute angle in degrees are known. The equations below are derived from the three ratios discussed previously. Select the equation that agrees with the problem, but be sure that the two factors on the right side of the equation are known factors.

Table 1
Trigonometric Ratios (Functions)

Angle, °	Sine	Cosine	Tangent	Angle, °	Sine	Cosine	Tangent
0	0.0000	1.0000	0.0000	45	0.7071	0.7071	1.0000
1	0.0175	0.9998	0.0175	46	0.7193	0.6947	1.036
2	0.0349	0.9994	0.0349	47	0.7314	0.6820	1.072
3	0.0523	0.9986	0.0524	48	0.7431	0.6691	1.111
4	0.0698	0.9976	0.0699	49	0.7547	0.6561	1.150
5	0.0872	0.9962	0.0875	50	0.7660	0.6428	1.192
6	0.1045	0.9945	0.1051	51	0.7772	0.6293	1.235
7	0.1219	0.9926	0.1228	52	0.7880	0.6157	1.280
8	0.1392	0.9903	0.1405	53	0.7986	0.6018	1.327
9	0.1564	0.9877	0.1584	54	0.8090	0.5878	1.376
10	0.1737	0.9848	0.1763	55	0.8192	0.5736	1.428
11	0.1908	0.9816	0.1944	56	0.8290	0.5592	1.483
12	0.2079	0.9782	0.2126	57	0.8387	0.5446	1.540
13	0.2250	0.9744	0.2309	58	0.8481	0.5299	1.600
14	0.2419	0.9703	0.2493	59	0.8572	0.5150	1.664
15	0.2588	0.9659	0.2680	60	0.8660	0.5000	1.732
16	0.2756	0.9613	0.2868	61	0.8746	0.4848	1.804
17	0.2924	0.9563	0.3057	62	0.8830	0.4695	1.881
18	0.3090	0.9511	0.3249	63	0.8910	0.4540	1.963
19	0.3256	0.9455	0.3443	64	0.8988	0.4384	2.050
20	0.3420	0.9397	0.3640	65	0.9063	0.4226	2.145
21	0.3584	0.9336	0.3839	66	0.9136	0.4067	2.246
22	0.3746	0.9272	0.4040	67	0.9205	0.3907	2.356
23	0.3907	0.9205	0.4245	68	0.9272	0.3746	2.475
24	0.4067	0.9136	0.4452	69	0.9336	0.3584	2.605
25	0.4226	0.9063	0.4663	70	0.9397	0.3420	2.748
26	0.4384	0.8988	0.4877	71	0.9455	0.3256	2.904
27	0.4540	0.8910	0.5095	72	0.9511	0.3090	3.078
28	0.4695	0.8830	0.5317	73	0.9563	0.2924	3.271
29	0.4848	0.8746	0.5543	74	0.9613	0.2756	3.487
30	0.5000	0.8660	0.5774	75	0.9659	0.2588	3.732
31	0.5150	0.8572	0.6009	76	0.9703	0.2419	4.011
32	0.5299	0.8481	0.6249	77	0.9744	0.2250	4.332
33	0.5446	0.8387	0.6494	78	0.9782	0.2079	4.705
34	0.5592	0.8290	0.6745	79	0.9816	0.1908	5.145
35	0.5736	0.8192	0.7002	80	0.9848	0.1737	5.671
36	0.5878	0.8090	0.7265	81	0.9877	0.1564	6.314
37	0.6018	0.7986	0.7536	82	0.9903	0.1392	7.115
38	0.6157	0.7880	0.7813	83	0.9926	0.1219	8.144
39	0.6293	0.7772	0.8098	84	0.9945	0.1045	9.514
40	0.6428	0.7660	0.8391	85	0.9962	0.0872	11.430
41	0.6561	0.7547	0.8693	86	0.9976	0.0698	14.301
42	0.6691	0.7431	0.9004	87	0.9986	0.0523	19.081
43	0.6820	0.7314	0.9325	88	0.9994	0.0349	28.636
44	0.6947	0.7193	0.9657	89	0.9999	0.0175	57.290
				90	1.0000	0.0000	Infinity

Unknown *Known*

(1) $a = c \sin \theta$

(2) $a = b \tan \theta$

(3) $b = a/\tan \theta$

(4) $b = \cos \theta$

(5) $c = a/\sin \theta$

(6) $c = b/\cos \theta$

Power and Power Factor

Alternating current has two characteristics that are not present in DC circuits. These are inductive reactance and capacity reactance. Inductive reactance is much more common. It is caused by the changing magnetic field produced around a conductor carrying AC, cutting the conductor and inducing a counter voltage that tends to cause the current to continue to flow in the same direction after the applied voltage has reversed. This counter emf causes the current to lag behind the voltage and use up power since the current is trying to go in an opposite direction from the applied voltage. This power is sometimes called *wattless power* because no useful work is being done. Not only does this wattless power do no useful work, but it causes heat in the coils, which is sometimes very objectionable.

Since all the power generated is not put to useful work in most AC circuits, there is what is called *apparent power* and *true power.* True power is measured in watts, just as power in DC circuits is measured. Apparent power is measured in volt-amperes or kilovolt-amperes. It is found by multiplying volts by amperes or kilovolts by amperes. It is almost always greater than true power. The ratio of true power to apparent power is called the *power factor.* Since the apparent power can never be less than the true power and is usually greater, the power factor can never be greater than unity, or one, and is usually less than one.

The power factor is spoken of as being leading, lagging, or 100 percent if true power and apparent power are the same. The current will lag behind the voltage in a series circuit if the inductive reactance is greater than the capacity reactance. It will lag behind the voltage in a parallel circuit if the current through the inductive part is greater than the current through the capacity part of the circuit. The power factor is said to be *lagging* if the current lags behind the voltage and *leading* if the current leads the voltage.

A capacitor consists of two or more conductors separated by an insulator. Usually capacity reactance is caused by capacitors or overexcited synchronous motors, but there is a certain amount of capacity reactance in an AC circuit where two wires run side by side for a long distance.

If a capacitor, or condenser, as it is sometimes called, is connected in an AC circuit, its plates are alternately charged and discharged. As the electrons surge in one direction, they leave one side of the capacitor and go to the other side. When the applied voltage drops off below the potential difference between the plates of the capacitor, the electrons start feeding back in the opposite direction before the voltage has reversed. Hence, capacitors cause the current to lead the voltage, or cause a leading power factor. Capacity reactance would also cause some power to be wasted because of the current and voltage opposing each other in part of each cycle.

Since inductive reactance causes a lagging power factor and capacity reactance causes a leading power factor, they can be combined to cancel each other and thereby produce almost 100 percent power factor. Most AC circuits have a lagging power factor. Therefore, capacity is quite often placed in the circuit in order to improve the power factor.

If the circuit has 100 percent power factor, the current and voltage rise and fall at the same time and are said to be "in phase." If the current either leads or lags the voltage, they are said to be "out of phase" with each other. Sometimes, as in the case of the capacitor-start motor, it is desirable to have the current in one winding lead the current in the other winding. By using a capacitor in series with the starting winding, the current in it can be made to lead the current in the running winding, thus giving the motor a better starting torque with less starting current.

Measuring Electric Current

The number of amperes indicates the rate of flow of electricity through wires, just as the number of gallons per minute indicates the rate of flow of water through a pipe or as the number of cubic feet per second indicates the rate of flow of water in a river. The less resistance (ohms), the more amperes there will be in a circuit for a given voltage or pressure, just as when water is forced through pipes by pressure.

A device called an ammeter, when connected to a circuit, indicates the current in that circuit in amperes. Figure 4 shows two ammeters, and figure 8 is a diagram of one connected in a circuit. Ammeters for alternating current and for direct current are usually different in construction and should be used only on the current for which they are intended. Some types can be used for both kinds of current, but they have some disadvantages.

Measuring Voltage

Voltage, or electrical pressure, is measured in volts by a voltmeter. It must be connected between those two points of a circuit across which the voltage is desired—for instance, across the terminals of a motor (see fig. 8).

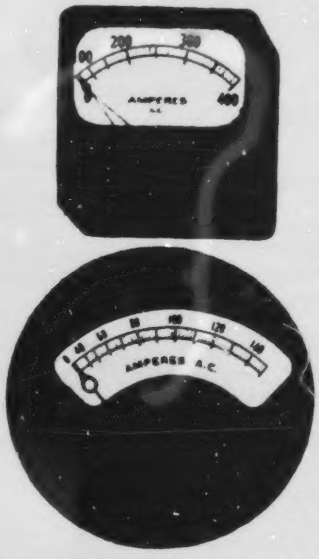

Fig. 4. AC ammeters: rectangular and round switchboard types

In construction, voltmeters resemble ammeters, but they use much smaller currents and have a series internal resistance. Like ammeters, the more accurate types of voltmeters are built for only one kind of current and cannot be used interchangeably. A DC voltmeter designed for switchboard mounting is shown in figure 5, along with a portable voltmeter.

Defining and Measuring Power

Power is defined as the rate of doing work. A direct current does work in proportion to its current strength and to the voltage at which it operates in the circuit. Its power is equal to the product of the current and voltage.

Electric power is measured in watts. Mechanical power is measured in horsepower. One horsepower equals very nearly 746 watts. One watt is a rather small unit of power. So, when speaking of the power required by motors, the term kilowatt (1,000 watts) is used.

To find the power being delivered to a motor, multiply the current (in amperes) by the potential (in volts) to obtain the power (in watts): $P = EI$, or watts = volts × amperes, where P is power, E is voltage, and I is current. To obtain the power in kilowatts, divide by 1,000.

To obtain the power delivered to an AC motor, one cannot merely multiply effective amperes by effective volts. This is because the windings of such a motor constitute a high inductance that forces the current to lag behind the voltage, as indicated in figure 6.

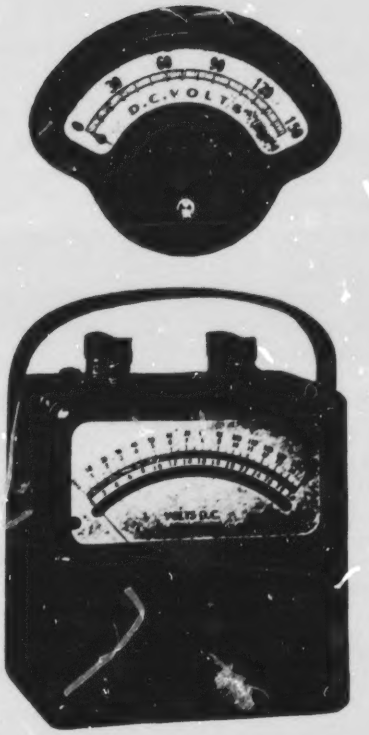

Fig. 5. DC voltmeters: switchboard and portable types

If the circuit contains no inductance or capacitance, the current will rise and fall with voltage, as shown in figure 7. A circuit containing only electric lamps or electric heating devices would be of this nature. At any instant, the product of volts and amperes will give watts at that instant, and the power will vary as shown, rising and falling with the current and voltage. The product of the effective current and effective voltage will then be real power for circuits without inductane or capacitance just as in the case of direct current.

If the circuit contains inductance, however, and motor circuits always contain it, the product of the effective current and effective voltage will be greater than the real power. This "apparent power" is measured in volt-amperes, or more often in a unit 1,000 times as large, the *kilovolt-ampere* (kva). The reason for this may be learned by studying figure 7, where the power is plotted at every instant throughout the cycle as the product of volts and amperes at the same instant.

Most of the time the power is positive, but when either the current or voltage is zero, their product must also be zero. Also, when the voltage is positive and the current negative, or vice versa, the product is negative and we shall have negative power. If this curve represents the power by an induction motor, the motor will draw power from the line most of the time, but will be returning power to the line when the power has a negative value. The real power, then, will be the net flow of power as represented by the rate that the motor takes from the line and that it never sends back.

The real power is expressed in watts or kilowatts and cannot be determined from ammeter and voltmeter readings except in the rare cases when there is neither inductance nor capacitance in the circuit. Wattmeters are generally used to measure power. These instruments are connected into a circuit as shown in figure 8. Note that the

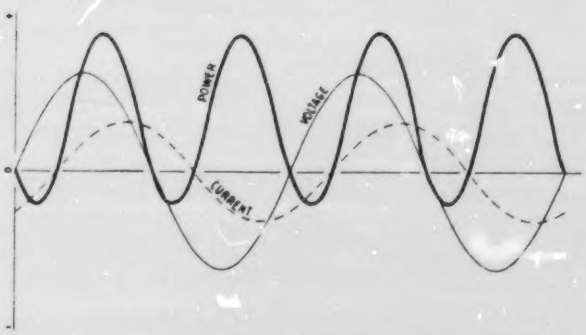

Fig. 6. Current, voltage, and power in a circuit containing inductance

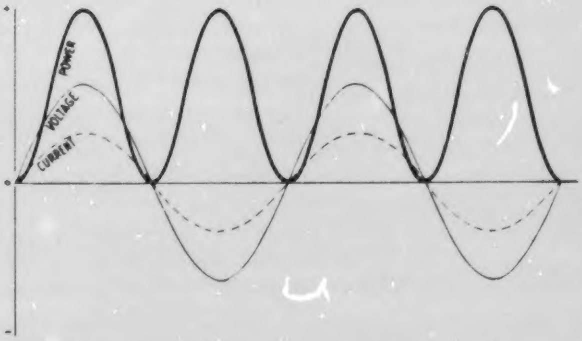

Fig. 7. Current, voltage, and power in a circuit operating at unity power factor

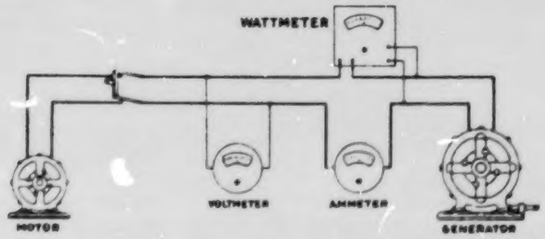

Fig. 8. In this circuit, an ammeter is connected in series, a voltmeter in parallel, and a wattmeter in both ways. This applies equally well to DC and AC systems.

Fig. 9. Portable wattmeter

wattmeter measures both the current and the voltage. The instrument contains two coils, one of which must be connected across the lines to measure potential and the other in series with the circuit to measure current. A wattmeter reads in terms of real power. A portable single-phase or DC wattmeter is shown in figure 9.

Power Factor

In an AC power system, the voltage and current follow an approximate sine wave. They build up from zero to a maximum in one direction, then diminish to zero, build up again to a maximum but in the opposite direction, and again diminish to zero, thus completing one cycle or two alternations and 360 electrical degrees.

The power factor is said to be 1.0, or unity, if the voltage and current reach their respective maximum values at the same time. However, in most AC systems, the voltage reaches its maximum value in a given direction before the current attains its maximum value. Then the current is said to lag behind the voltage. This lag may be measured in degrees.

The lagging of the current is caused by certain inherent characteristics of the system, which have a tendency to choke back or oppose any change in direction of the current flow. Such devices as transformers, induction motors, electric welders, and electric furnaces are the chief causes of lagging current.

The actual current drawn by apparatus of this class may be considered as having two components, one known as the *magnetizing current*, or that current which must overcome the choking effect produced by the characteristics of the apparatus and that lags 90 electrical degrees behind the voltage. The value of this lagging current is zero when the voltage has reached its maximum value. This lagging, or magnetizing, current is called the *reactive current*. The other component is known as the *active current*, and it is in phase with the voltage. This active current and the voltage reach maximum values simultaneously.

The actual line current is therefore the resultant of the reactive and active currents. Furthermore, it is the current that would be registered were an ammeter connected in the circuit. Since one component is lagging 90 electrical degrees, or at right angles to the voltage, the resultant or actual line current, of which this component is a part, must thus be out of phase with the voltage and lag behind it. The degree or amount that it lags depends on the magnitude of this reactive current component and is a measure of the power factor.

In figure 10, the voltage is represented by the line OE. The line OI represents the actual line current, as measured by an ammeter in the circuit, which lags behind the voltage by the angle ϕ. The active current component in phase with the voltage is OA, and the reactive or magnetizing component is AI, 90 degrees out of phase with the voltage. The power factor is the ratio of the active current component to the actual current:

$$\text{power factor} = \frac{OA}{OI}$$

$$\text{and } \frac{OA}{OI} = \text{cosine } \theta$$

If the value of OI is the actual current as read by an ammeter in one phase of a three-phase circuit, then

$$\text{kva} = \frac{\sqrt{3} \times OE \times OI}{1{,}000}$$

This is the apparent power. The actual power is

$$\text{kw} = \frac{\sqrt{3} \times \text{volts} \times \text{amperes} \times \text{cosine } \theta}{1{,}000}$$

It is therefore obvious that kva and kw are the same and equal at 1.0, or unity, power factor, but at power factors below unity, the current for a given kw changes inversely with the power factor. That is, as the power factor goes below unity, the current increases proportionately.

Power factor is also the ratio of real power to the apparent power. The former is measured in kw by a wattmeter, and the latter in kva by a voltmeter and ammeter. Therefore, power factor is also equal to kw/kva.

Measuring Power in Two-Phase and Three-Phase Circuits

Wattmeters must be used to measure the power in two- and three-phase circuits. A two-phase circuit can be considered as two single-phase circuits. Each phase is measured separately, and the total power equals the

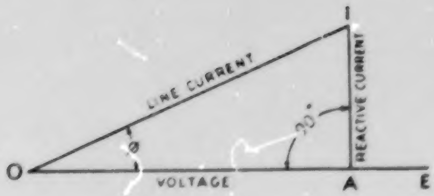

Fig. 10. Representation of voltage

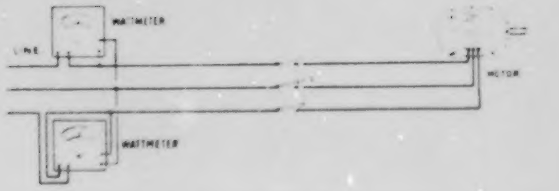

Fig. 11. Method of connecting two wattmeters

sum of the two readings. Sometimes, when the power in both phases is known to be equal, one phase may be measured and the reading doubled.

To read the power in a three-phase circuit, a polyphase wattmeter can be used or two single-phase wattmeters connected as shown in figure 11. Note that the current coil of each wattmeter is connected in one line, and that the potential coil of each wattmeter is connected from the line in which the current coil is connected to the third line. For power factors above 50 percent, the power in the three-phase system will be the sum of these two wattmeter readings. At 50 percent, one wattmeter will read zero. At still lower power factors, this wattmeter will read negatively. Its current connections should be reversed, and the difference between the readings of the two instruments will then be the true power.

The kva output or input of any machine may be computed as follows:

$$\text{apparent power} = \frac{EI}{1{,}000}$$

$$= \frac{\text{volts} \times \text{amperes}}{1{,}000} = \text{kva}$$

For two-phase, when both phases have equal currents and equal voltages,

$$\text{apparent power} = \frac{2EI}{1{,}000}$$

$$= \frac{\text{volts} \times \text{amperes} \times 2}{1{,}000} = \text{kva}$$

For three-phase, when the currents are equal in all three wires and the voltages between any pair of wires are equal,

$$\text{apparent power} = \frac{\text{current in any wire} \times \text{voltage between two wires} \times 3}{1{,}732}$$

$$= \frac{3EI}{1{,}732}$$

$$= \frac{\text{volts} \times \text{amperes} \times 3}{1{,}732} = \text{kva}$$

or

$$\text{kva} = \frac{\text{volts} \times \text{amperes} \times 1.73}{1{,}000}$$

The kilowatt output or input of any machine may be found by multiplying the kva output or input, as the case may be, by the power factor:

$$P = \text{kva} \times \text{power factor} = \text{kw}$$

Measuring Electrical Energy

Energy is the ability to do work. It is most commonly expressed in terms of the rate at which the work is done and the time used in doing it. Since the rate of doing work is power, energy is equal to the product of power and time. For example, a 5-hp motor requires 2 hours to pump the water to fill an elevated storage tank. The energy represented by this work is five times two power-time units, or 10 horsepower-hours. Now a 10-hp motor could do the same work in half the time, but the energy used would still be 10 horsepower-hours.

Mechanical energy is measured in horsepower-hours. Electrical energy is measured in watt-hours or kilowatt-hours. A kilowatt-hour equals a thousand watt-hours and is the unit more commonly used by power companies in selling energy.

If the power is known to remain constant on a circuit for a particular time interval, the energy can be determined by measuring the power with a wattmeter and multiplying this reading by the time in hours. For instance, a 25-hp three-phase motor running on constant voltage and constant load is observed for 40 minutes to have a steady combined reading of 21 kilowatts by the two-wattmeter method of measuring power shown in figure 11. The energy taken by the motor during this period is 21 kilowatts times two-thirds of an hour, or 14 kilowatt-hours.

It is very exceptional for both the load and voltage on a circuit to remain constant for any great length of time. Thus, the method of measuring energy just described is not practical. To be practical, the measuring instrument must be sensitive to all changes in power, and its recording element must sum up the power demand continuously for small intervals of time. An instrument that does this may be called an integrating wattmeter, but it is generally known as a *watt-hour meter* because its dials record the watt-hours (more commonly kilowatt-hours) of energy passed through it. Such a meter of the switchboard type is shown in figure 12. This polyphase meter consists of two wattmeter elements working on a single spindle. The watt-hour meters used in residences are smaller and almost always have only one single-phase element. Table 2 shows conversion formulas for finding amperes, kilowatts, the power factor and so on.

Test to Determine Output and Efficiency of a Motor

The mechanical output of a motor is most commonly measured by means of the Prony brake test. As shown in figure 13, this brake consists of two blocks shaped to fit around the pulley of the motor. By means of two long bolts with hand wheels at the top, the pressure of the blocks against the

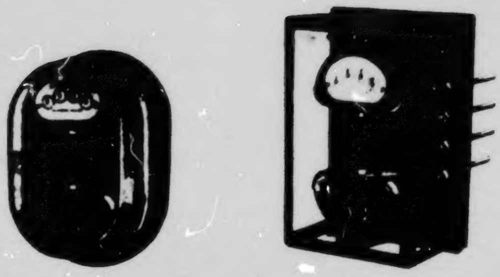

Fig. 12. Watt-hour meters

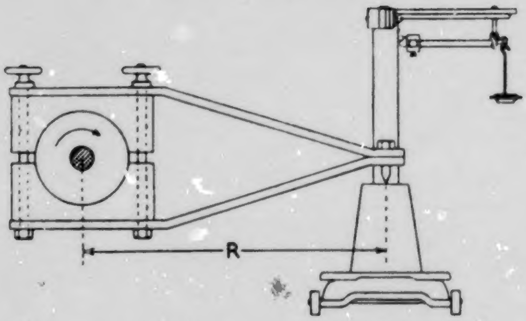

Fig. 13. The Prony brake test as applied to the pulley of a motor

pulley can be varied. Two bars fastened to the top and bottom of the brake form an extension arm by which the torque is measured as the net reading on the scale in pounds. The radius factor R is measured in feet from the center of the shaft perpendicularly to the bearing point on the scale.

The mechanical power of the motor equals its torque times the distance through which it operates per minute:

$$P = \frac{T \times 2\pi \times \text{rpm}}{33{,}000}$$

Where: P = power in horsepower
T = torque in foot-pounds
2π = 6.2832 (the ratio of the circumference to the radius)
rpm = speed, in revolutions per minute
33,000 = the number of foot-pounds per minute equivalent to 1 hp

As an example, take a test of a 40-hp motor, for which the force was 55 lb, the radius 2.5 ft, and the speed 1,440 rpm. The power then delivered was:

$$\frac{55 \times 2.5 \times 6.2832 \times 1{,}440}{33{,}000} = 37.7 \text{ hp}$$

To find the efficiency, we must measure (by means of a wattmeter or other suitable method) the input to the motor at the same time that the output is determined. Both output and input are then converted to the same unit, preferably watts, and the efficiency is found by applying the formula:

$$\text{efficiency in percentage} = \frac{\text{output}}{\text{input}} \times 100$$

A more accurate method is to use either a dynamometer for measuring the output or to calculate the efficiency by the loss methods as established by the American Institute of Electrical Engineers (A.I.E.E.).

Synchronous Speed of a Motor

The term *synchronous speed* applies only to AC motors. It is the speed of rotation of the revolving field pro-

Table 2
Conversion Formulas

TO FIND	DIRECT CURRENT	ALTERNATING CURRENT	
		Single Phase	† Three Phase
Amperes When Horse Power (Input) is Known	$\frac{\text{H.P.} \times 746}{\text{Volts} \times \text{Efficiency}}$	$\frac{\text{H.P.} \times 746}{\text{Volts} \times \text{Efficiency} \times \text{P.F.}}$	$\frac{\text{H.P.} \times 746}{\text{Volts} \times 1.73 \times \text{Efficiency} \times \text{P.F.}}$
Amperes When Kilowatts is Known	$\frac{\text{KW} \times 1000}{\text{Volts}}$	$\frac{\text{KW} \times 1000}{\text{Volts} \times \text{P.F.}}$	$\frac{\text{KW} \times 1000}{\text{Volts} \times 1.73 \times \text{P.F.}}$
Amperes When kva is Known		$\frac{\text{kva} \times 1000}{\text{Volts}}$	$\frac{\text{kva} \times 1000}{\text{Volts} \times 1.73}$
Kilowatts	$\frac{\text{Amperes} \times \text{Volts}}{1000}$	$\frac{\text{Amps.} \times \text{Volts} \times \text{P.F.}}{1000}$	$\frac{\text{Amps.} \times \text{Volts} \times 1.73 \times \text{P.F.}}{1000}$
kva		$\frac{\text{Amps.} \times \text{Volts}}{1000}$	$\frac{\text{Amps.} \times \text{Volts} \times 1.73}{1000}$
Power Factor	(P.F.)	$\frac{\text{Kilowatts} \times 1000}{\text{Amps.} \times \text{Volts}}$ or $\frac{\text{KW}}{\text{kva}}$	$\frac{\text{KW} \times 1000}{\text{Amps.} \times \text{Volts} \times 1.73}$ or $\frac{\text{KW}}{\text{kva}}$
Horse Power (Output)	$\frac{\text{Amps.} \times \text{Volts} \times \text{Efficiency}}{746}$	$\frac{\text{Amps.} \times \text{Volts} \times \text{Efficiency} \times \text{P.F.}}{746}$	$\frac{\text{Amps.} \times \text{Volts} \times 1.73 \times \text{Efficiency} \times \text{P.F.}}{746}$

Power Factor and Efficiency when used in above formulas should be expressed as decimals
† For 2 phase, 4 wire substitute 2 instead of 1.73
† For 2 phase, 3 wire substitute 1.41 instead of 1.73

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Table 3
Synchronous Speeds

60 Cycles		25 Cycles	
No. of Poles	Rev. per Min.	No. of Poles	Rev. per Min.
2	3,600	2	1,500
4	1,800	4	750
6	1,200	6	500
8	900	8	375
10	720	10	300
12	600	12	250
14	514	14	214
16	450	16	187
18	400	18	167
20	360	20	150
22	327	22	136
24	300	24	125
26	277	26	115
28	257	28	107
30	240	30	100

duced by the primary winding. The synchronous motor is the only one in which the synchronous speed is the same as the full-load speed. As explained earlier, the speed of the synchronous motor in revolutions per second equals the frequency of its power supply circuit divided by the number of pairs of poles of the motor.

Synchronous speeds are more commonly stated in revolutions per minute. For the two common frequencies of 60 and 25 cycles per second, synchronous speeds are given in table 3. Table 3 is derived by use of the rule above. It shows how the standard speeds of AC motors are restricted by the number of poles used in their design, which must always be an even number, half of them north and half south.

With induction motors, the synchronous speed is the speed at which they would run if there were no "slip." Their no-load speed is just a little below synchronous speed. The latter is almost invariably given as the rated no-load speed.

Synchronous motors can be built for speeds much lower than those shown in table 3 by using still large numbers of poles. This necessitates a rotating member of large diameter.

Induction motors, as a rule, are much more compact machines with synchronous speeds seldom lower than 450 rpm on 60-cycle circuits.

Exercise

1. What is *impedance* in AC circuits, and what symbol is used to represent it?
2. What is the unit of measurement for impedance?
3. What is the phase relationship between the resistive elements and the reactive elements in AC circuits?
4. Define *power factor.*
5. How are true power and apparent power measured?
6. Define *wattless power.*
7. Why is it possible to arithmetically subtract one type of reactance from the opposite type of reactance in AC circuits?
8. What is meant by the term *low power factor?*
9. The reactance of a circuit can be calculated by determining the arithmetical difference between the inductive and capacitive reactance. Why is it that this resultant reactance cannot be added directly to the resistive value to find the total circuit value?

Section

I

Electrical Meters and Test Equipment

I-1. Measuring and Test Equipment

I-1

Measuring and Test Equipment

Objectives: After completing this assignment, you will be able to—

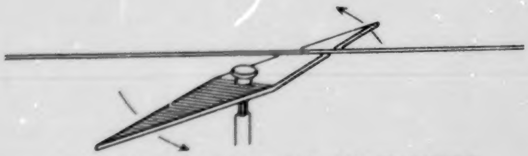
1. tell how voltmeters and ammeters are connected in relation to the load;
2. explain how the range of a voltmeter may be exceeded;
3. discuss the use of ohmmeters and voltmeters; and
4. discuss permanent-magnet meters.

Electrical meters are used to measure certain electrical quantities. They measure voltage, current flow in amperes, resistance to current flow in ohms, and power consumed in watts. Power factor meters, frequency meters, phase sequence indicators, and reactive factor meters are used also by some electrical workers. To keep electrical equipment operating efficiently, workers may need to make quick checkups and take accurate measurements. This job requires proper tools and workers who understand their use. The tools used in electrical measurement are electrical meters, expensive and delicate instruments. They can be easily put out of commission or even destroyed if they are carelessly handled or used. Repairers using these specialized tools can take better care of them and use them to the best advantage if they understand how and why certain meters are used to perform certain tasks.

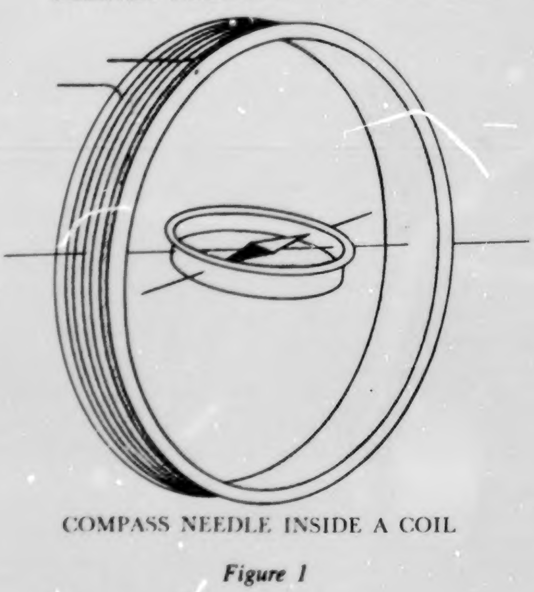
The first patent on an electrical measuring instrument was issued in 1881 to Jacques d'Arsonval, a French scientist and inventor, for a permanent magnet type of galvanometer. His work was based on the discovery of Oersted (1819) and the earlier developments of Faraday and Ampere. About 1887, Edward Weston, an English immigrant working in New Jersey, made a basic improvement on the Arsonval instrument and brought forth the first commercial type of galvanometer based on the permanent magnet.

Two types of electricity, AC and DC, have been discussed. In general, there are two types of electrical meters, one for measuring each type of electrical current.

The basic principle for electrical measuring meters is shown in figure 1. With the *compass needle and conductor,* if the compass needle is set parallel to the conductor, it will be deflected when the current flows in the conductor. The deflection is caused by a magnetic field set up around the conductor carrying the current. With the *compass needle inside a coil,* when the conductor is wound into a coil, the magnetic field



COMPASS NEEDLE AND CONDUCTOR



COMPASS NEEDLE INSIDE A COIL

Figure 1

Figures 2, 3, 5, and 12 in this assignment are taken from *The Instrument Sketchbook* (Weston Instruments, Division of Daystrom, Inc.) and are used with the permission of Weston Instruments.

strength is increased. The compass needle attempts to line up with this field that is perpendicular to the coil. The amount of deflection is determined by the number of amperes of current in the circuit.

DC Galvanometer

Most DC meters are patterned after Arsonval's original instrument, the galvanometer. They are basically a type of electric motor whose rotation is restricted by a steel spring. The coil is suspended on jeweled bearings and balanced precisely, so that it is very sensitive. It is suspended on a shaft between poles of a permanent magnet, designed so that its field is concentrated through the coil. An iron core inside the coil increases this concentration. When the coil is rotated, a pointer attached to the coil is carried across a scale, indicating that current is flowing.

The coil in a galvanometer tends to rotate in proportion to the amount of current it carries. It rotates so that its field is aligned with that of the permanent magnet, while the restricting spring holds it from rotating beyond 90 degrees and returns the pointer to the zero point. The galvanometer, while responding to the current in both directions, usually does not indicate amount. Since it is a very sensitive instrument, more than a small current will damage it. When equipped with proper shunts and calibration, it can be used as an ammeter. With suitable resistors and matching scale, it may serve as a voltmeter. The galvanometer is shown in figure 2.

DC Ammeter

At times it is necessary to measure direct current greater than the galvanometer can carry, and for this purpose the DC ammeter was developed. It, too, is a galvanometer but one that has been bypassed by a low-resistance shunt. This shunt is designed to carry an accurately known fraction of the current of the circuit. With the use of this known fraction, the galvanometer can then be marked or calibrated to indicate the amount of direct current flowing in the circuit.

Suppose, however, that the current to be measured is still too great to be measured by the galvanometer with a given shunt. To meet this problem, many ammeters have a number of shunts and a method of selecting the proper shunt for the current range being measured.

When a DC ammeter is used, three points should be kept in mind. First, the ammeter should be connected with the plus terminal toward the plus side and the negative terminal toward the negative side of the voltage source. If this is not done, the pointer of the meter can be damaged by the banging against the stop. Second, the range of the instrument selected must be great enough to handle the maximum current anticipated. Third, and this is very important, *an ammeter must be connected in series in a line.*

If this instrument were connected across two lines, the low resistance of the shunt would act as a short circuit, and the resulting heavy flow of current would probably destroy the instrument or the circuit to which it is connected. Voltmeters are connected across the line. The meter movement would be destroyed if a voltmeter were connected in series with a load.

A cutaway section of a DC ammeter is shown in figure 3. This is a permanent-magnet, moving-coil instrument. The details of the coil assembly are shown at *A* with the pointer at the top, the coil winding on the rectangular frame, and the spiral hairsprings at the top and bottom of the coil. *B* is a cutaway of the meter, and *C* shows details of the bearing and bearing adjustment of the coil assembly. The permanent magnet is mounted in the center of the moving coil with the magnetic circuit completed through the iron section around the outside of the coil assembly. The movement of the coil assembly works on the same principle as the mechanism described earlier.

DC Voltmeter

The DC voltmeter does not measure voltage. It measures the current passing through its coil. From this, the voltage is inferred. Although the DC voltmeter uses the same principle as the ammeter, there is no shunt. Instead, a high resistance (multiplier) is wired in series with the voltmeter. To measure the voltage dropped through any part of a DC circuit, the voltmeter is connected in parallel with this portion of the circuit. Since voltage is in direct proportion to current, the meter scale can be made to register in volts. Connection of additional series resistors to a voltmeter, by means of a switch, increases the range of that voltmeter to handle voltages that would otherwise be too great.

As with the ammeter, you must

Fig. 2. DC galvanometer

always connect a DC voltmeter plus to minus. One safe way to ensure that the range of the meter is adequate is to choose the largest range, attach the meter, and reduce the range of the meter until it can be read in the upper one-third of the scale. Remember to connect a DC voltmeter across the line or in parallel to the voltage being measured. If it is wired in series with a circuit, the high resistance of this meter would restrict the flow of current and impair the usefulness of the circuit.

Ohmmeter

The rugged, portable instrument used to measure the resistance, or check the continuity, of a circuit is called an ohmmeter. This instrument is a galvanometer that makes use of a dry-cell battery to provide a standard source of voltage. With the voltage standardized and the current indicated, the scale of the meter can be calibrated to read "ohms" of resistance since current, voltage, and resistance are proportional.

An ohmmeter has two leads, which are connected to the device whose resistance is to be measured. The dry-cell battery causes a current to flow through the meter, which is indicated on the scale as resistance. Before you use an ohmmeter, check the zero reading. Touch the two bare points of the leads together, and adjust a rotary switch on the case until the pointer indicates zero. This is done because a dry-cell battery loses strength and changes the reading of the meter. When using the ohmmeter, remember to disconnect the equipment whose resistance is to be measured from any external source of electricity. Since the meter action was designed for the voltage of a dry-cell battery, an outside voltage would probably destroy this meter. One important use of the ohmmeter is to make sure that an appliance or electrical system is properly grounded.

When using the ohmmeter to measure resistance, the unknown resistance RX is connected as shown in figure 4. The battery is the source of emf. At (A) the meter is calibrated in

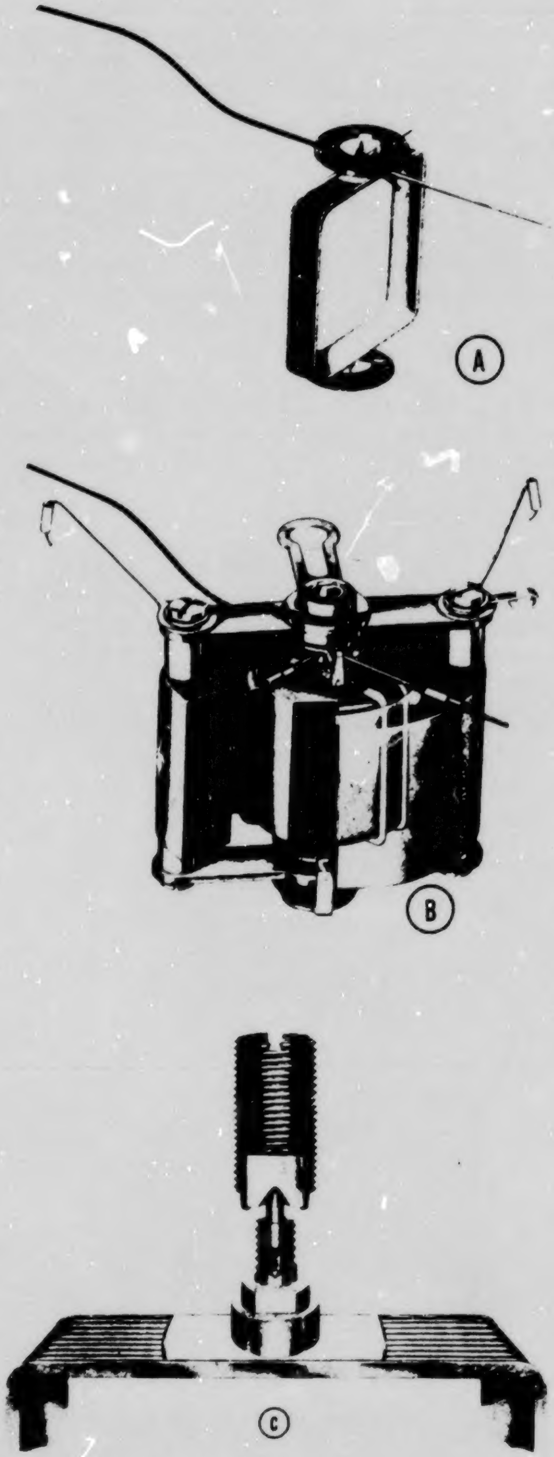


Fig. 3. DC ammeter

ohms of resistance. The variable resistance is used to zero the meter before making a resistance measurement. The ohmmeter circuit at view *A* shows a series-type ohmmeter, and the ohmmeter circuit at view *B* is called a shunt type because the unknown resistance is connected in parallel with the measuring meter.

Other methods may be used to measure resistance. One is by comparing a known resistance with an unknown resistance. The Wheatstone Bridge is an example of an instrument that uses this principle. It uses three known resistances to compare with the unknown resistance that is being measured. Although this is a very accurate method, it is neither rugged nor versatile enough for use in the field. A variation of the Wheatstone Bridge is used in the circuits of electronic control instruments.

Electrodynamometers

In permanent-magnet meters, one field is supplied by a permanent magnet and the other by a moving coil. This principle works well in a direct current but will not react fast enough to register an alternating current. One way to avoid the reversal of the moving coil would be to reverse both fields at the same time. This is done in the electrodynamometer.

The electrodynamometer uses two stationary field coils in series with a movable coil instead of the permanent magnet. This movable coil is attached to a central shaft on which it rotates inside of the two stationary coils. Spiral springs at each end of the central shaft provide a means of introducing current into the movable coil. When current flows through the coils, the movable coil attempts to line itself up with the field coils and is held back by the spiral springs. The more current that flows, the more the movable coil will attempt to rotate, and the more force exerted on the spring.

The movable coil is attached to a pointer that is carried across a scale until the springs stops the rotation. When the instrument is properly calibrated, this type of meter can measure AC or DC volts, or it can be used as an ammeter to measure AC or DC current. This is because the fields of the movable and fixed coils reverse at the same time. When both fields are reversed together, the motor action is still the same, and the force on the movable coil remains in the same direction. When used as an ammeter, the coils are wound with lower-resistance wire. When used as a voltmeter, the coils are wound with high-resistance wire to restrict the current flow through the meter. A high noninductive resistance is connected in series with the mechanism. Additional ranges are provided by extra resistances.

This type of instrument has one weak point. The springs that provide the restoring force to the moving coil and allow current to reach this coil must have a constant and precisely designed spring force. If more than a very little current flows through it, the temper of the spring metal could be damaged by heat, which would destroy the effectiveness of the meter. Therefore, it is doubly important with this type of meter that its range is not exceeded. Be sure that the range that is first used is the largest available. Lower value ranges can then be chosen until the meter can be read accurately.

Figure 5 shows such an electrodynamometer, which uses an electromagnetic field in place of a permanent magnetic field. The movable coil is shown at *A* in the drawing at the left, with the field coils shown at *B*. With proper scale calibraton, this instrument can be used on either AC or DC. Since the movable coil and the field coils are in series, their polarity reverses simultaneously, and the needle continues to move in the same direction. At left, above, is a cutaway of the dynamometer. At right, above, is the moving coil

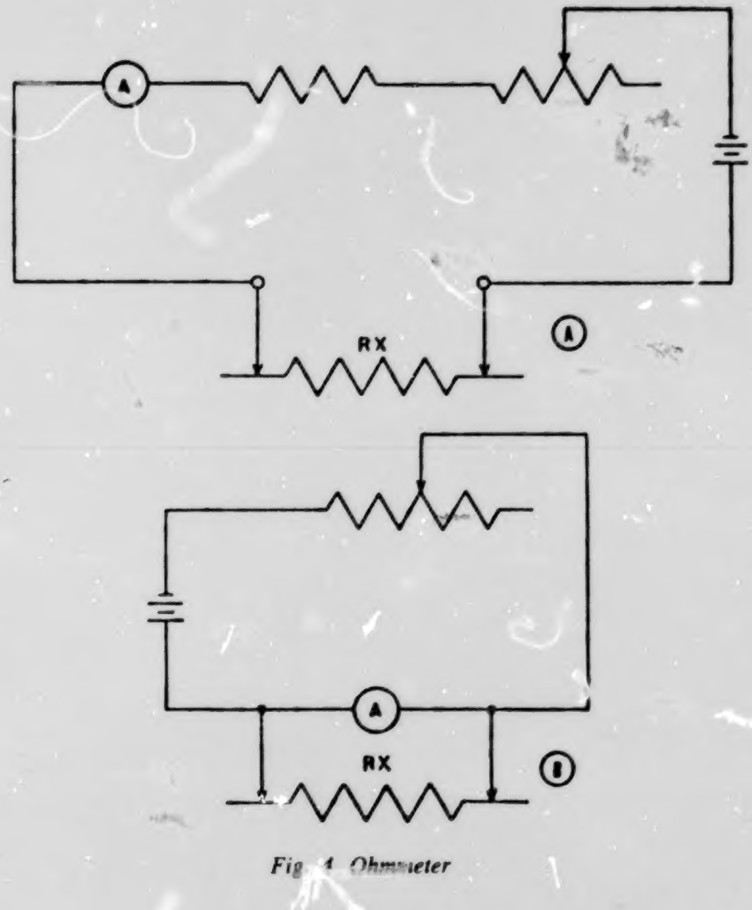


Fig. 4 Ohmmeter

assembly with the pointer and hairsprings at the top, the coil in the center of the shaft, and the damping vanes at the bottom of the shaft.

Rectifier Meters

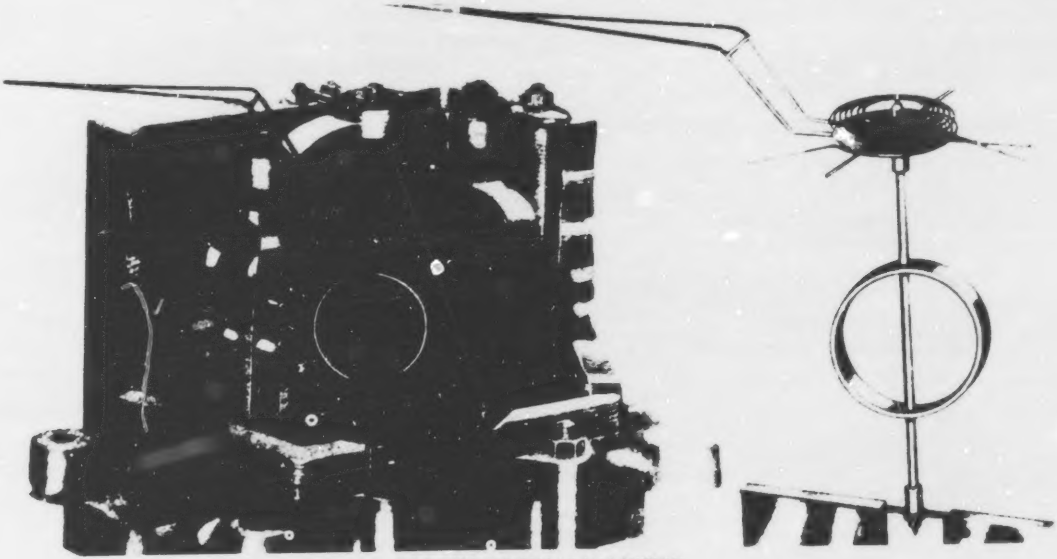
Permanent-magnet meters are more sensitive than other types of meters. In order to use them in measuring AC circuits, rectifiers have been placed in the meter. A *rectifier* is a device that will allow current to flow in one direction only. In this way a permanent-magnet meter could be used in an AC circuit. One application of this meter is in the portable AC-DC meters used by electrical repairers.

Most AC meters measure the effective current or voltage, which is 0.707 times the maximum amplitude of the current or voltage. Such a measurement is also called the *rms* (root-mean-square) of the electrical quantity. It is the square root of the mean (average) value of the square of the quantity. For this reason the scale graduations on AC meters are generally nonuniform. The scale graduations on DC meters are generally uniform.

Safety Precautions

There is always inherent danger in testing electrical equipment. Workers should be thoroughly familiar with the equipment under test before working on it, and should keep in mind that high voltages may appear at unexpected points in defective equipment. The folowing list of safety precautions should always be observed.

1. It is good practice to remove power leads before connecting test leads to high-voltage points. If this is impractical, be especially careful to avoid accidental contact with equipment racks and other objects that can provide a ground. Working with one hand in your pocket and standing on a properly insulated floor lessens the danger of shock.
2. Filter capacitors may store a charge large enough to be lethal. Therefore, discharge filter capacitors before attaching test leads.
3. Remember that leads with broken insulation provide the additional hazard of high voltages appearing at exposed points along the leads. Check test leads for frayed or broken insulation before working with them.
4. To lessen the danger of accidental shock, disconnect test leads after they are used.
5. Remember that the risk of severe shock is only one of many possible hazards. Even a minor shock can place you in danger of more serious risks,



ELECTRODYNAMOMETER

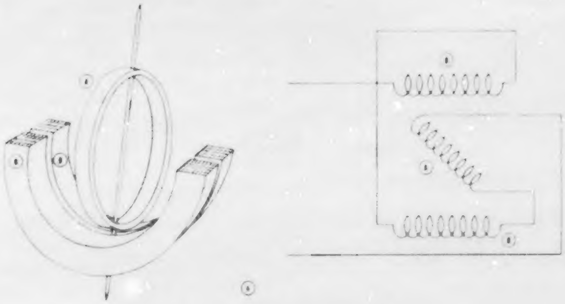


Fig. 5. Electrodynamometer

such as a bad fall or contact with a source of higher voltage.

6. The experienced worker continuously guards against injury and does not work on hazardous circuits unless another person is available to assist in case of an accident.

Portable Multimeters

The basic DC permanent-magnet, moving-coil meter is used in most portable volt-ohm-milliammeters. Since one instrument is used for all measurements, it must contain a bridge rectifier for the AC section to convert AC into pulsating DC. The movement of a meter is also identified by the amount of current it takes to cause a full-scale deflection of the pointer. In other words, the full-scale sensitivity of a meter is the amount of current it takes to cause a full-scale deflection of the meter pointer. The two meters discussed here each have a 50-microampere movement (50 μa is 50 millionths of an ampere, or 0.000050 amp). All meter readings (volts, amperes, or ohms) depend on the amount of current flow through the meter movement.

The multirange **RCA Model WV-38A volt-ohm-milliammeter** is shown in figure 6. Notice the plastic screw on the bottom front of the meter. The meter pointer should rest exactly on zero when not in use. If necessary, adjust the pointer to zero by turning the plastic screw. The switch at the left of the panel allows the operator to select the circuitry for −DC, +DC, or AC measurement.

The center switch is used to select any one of five voltage ranges, with full-scale values of 2.5, 10, 50, 250, and 1,000 volts. These voltages are obtained by adding successively higher values of resistance in series with the meter circuit.

The switch is used to select any one of five current ranges with full-scale values of 1 ma (milliampere), 10 ma, 100 ma, 500 ma, or 10 amp. These current ranges are obtained by switching appropriate values of shunt resistance across the meter circuit.

The switch is used also to select any one of three resistance ranges RX 1 (0–2,000 ohms), RX 100 0–200,000 ohms), or RX 10,000 (0–20,000,000 ohms). The basic scale 0–2,000 ohms is used for reading on all ohm ranges. Simply multiply the scale numbers by 1, 100, or 10,000 as indicated by the selector switch.

The switch on the right is the zero ohms adjust potentiometer, which is connected in series with the meter circuitry and one or more dry-cell batteries. The ohms adjust switch is used to adjust the voltage so that a full-scale deflection of the meter (zero on the ohms scale) can be obtained as the battery voltage decreases because of use and age.

Before the meter is used for reading ohms on any range, the test prods should be shorted together, and the potentiometer should be adjusted for that range until the meter pointer is on zero on the ohms scale (right side of the meter). If the meter cannot be adjusted to zero, a weak battery is indicated. The battery should be replaced with a new one. The test leads must be plugged into the appropriate jacks before a measurement is made.

Care and Safety Precautions. The following cautions should be observed for safe and successful resistance measurements and for proper care of the meter.

1. Before making a resistance measurement, be sure that no voltage is present in the circuit under test. An energized circuit will destroy the meter.

2. Do not try to measure the resistance of a meter movement because the high current from the test battery will destroy the meter movement.

3. Do not touch any metal parts of the test leads or the circuit when using the high ohm ranges. It is not dangerous, but your body resistance can cause a serious measurement error.

4. After making a resistance test, do not leave the center selector switch on the ohms section. The current flow through the resistor network in the meter will discharge the test battery.

5. If you are using the meter to check continuity, use one of the higher ohmic ranges because a fairly high battery current will be used on the RX 1 range. Repeated use on low range will discharge the test battery.

6. Get in the habit of double-checking the position of the switches

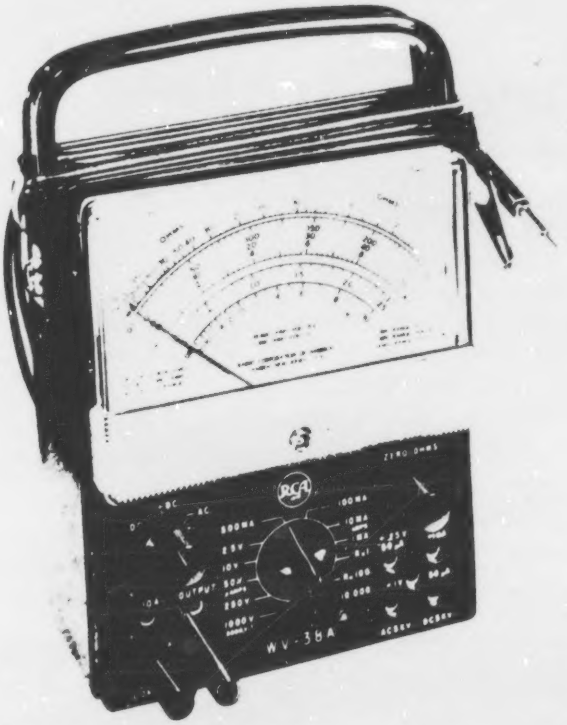


Fig. 6. Type of multimeter: the RCA WV-38A volt-ohm-milliammeter

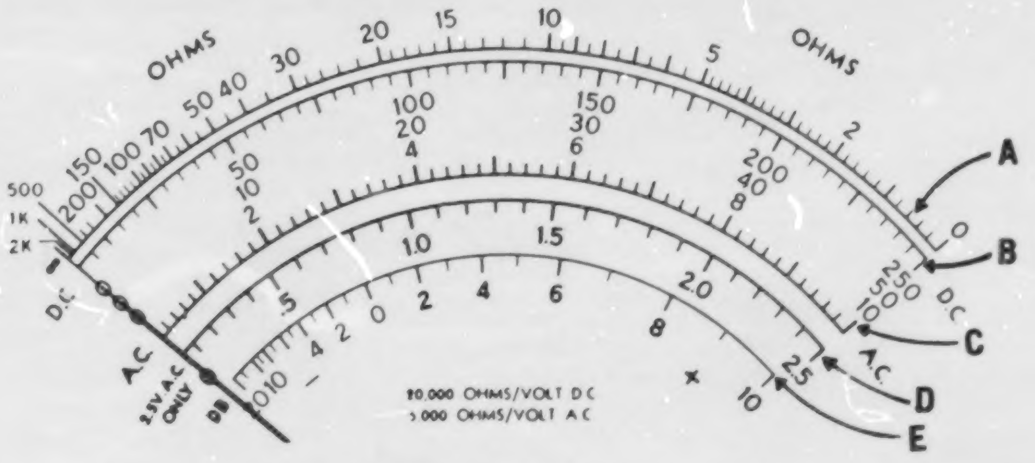


Fig. 7. Meter scales on a multimeter

and jacks before making a measurement. The meter can be burned out by applying voltage when the selector is set on the current or ohms position.

7. Treat a test meter like a fine watch. Do not leave it where it will be subjected to severe vibrations or severe temperature changes.

Ohms Measurement. Read ohms from the upper scale A in figure 7. Figure 7 shows the meter pointer at rest and at zero for every scale except the ohms scale. It is at infinity on the ohms scale. A zero reading on the ohms scale requires a full-scale deflection of the meter pointer to the right (a direct connection of the meter test leads). The steps for making a measurement follow:

1. Insert one test lead into the meter jack marked *com* (common) and the other one into the jack marked *V-Ω-A*.

2. Set the center selector switch to the appropriate ohms range.

3. Short the two test leads together, and adjust the zero ohms potentiometer so that the pointer indicates exactly zero (0) on the ohms scale A. This operation should be repeated if another range is selected.

4. Connect the test leads to the resistance to be measured.

5. Read the resistance indication on scale A. Since this same scale is used for all resistance measurements, the reading must be multiplied by the selected range factor (RX 1, RX 100, or RX 10,000).

6. Move the selector switch off of the ohms section to prevent discharging the test battery through the resistor network of the meter.

DC Measurement. All DC measurements (voltage and current) will be read from scale B. The numbers between scale B and scale C allow a direct reading of three ranges of voltage (0–10, 0–50, or 0–250). A 0–25-volt reading may be obtained by multiplying a reading on the 0–250-volt range by 0.01. A 250-volt to 1,000-volt reading may be obtained by multiplying a reading on the 0–10 range by 100.

1. Insert the black test lead into the common (−) jack and the red lead into the V-Ω-A jack.

2. Turn the left function switch to the +DC position.

3. Set the center selector switch to a position considerably higher than the voltage to be measured. A lower position may allow the meter pointer to peg, which may result in a bent pointer. Also, the current flow through the meter may become excessive and destroy the meter.

4. Connect each test lead with the proper polarity to the voltage source to be measured. The meter pointer will move off scale to the left and may be damaged if the leads are connected to the wrong polarity.

5. Reset the center selector switch to a position that gives a suitable pointer deflection.

6. Read the DC voltage from scale B as described previously.

These same six steps are used to measure currents from 0–1 ma, 1–10 ma, 10–100 ma, and 100–500 ma, except that the center selector switch must be turned to the appropriate milliampere current position. All current measurements are read on the 0–10 range on the B scale except a measurement from 100–500 ma. This measurement is read on the 0–50 range. Follow this procedure for an accurate reading of each measurement:

1. For a 0–1 ma measurement, multiply a reading between the 0–10 range by 0.1.
2. A 1–10 ma measurement may be read directly between the 0–10 range.
3. For a 10–100 ma measurement, multiply a reading on the 0–1 range by 10.
4. For a 100–500 ma measurement, multiply a reading on the 0–50 range by 10.
5. For a 500-ma to 10-amp measurement, set the center selector switch on the 10-ma position and plug the red test lead into the + 10-amp jack on the right side of the instrument and read the measurement between the 0–10 range.

AC Voltage Measurement. To measure AC voltages, set the left function switch to AC. Plug the black test lead into the V-Ω-A jack on the meter. The same numbers of the three ranges between the B and C scales that were used to measure DC (0–10, 0–50, and 0–250) must be applied to the points of the C scale. The same steps that were used to measure DC voltages are used to measure AC voltages except for the 0–2.5-volt range. The D scale and the numbers below it are used to read measurements in the 0–2.5-volt range.

The **Triplet Model 630** has the same five basic scales, but the ranges of the numbers are different (see fig. 8). For easier reading, the Ω and AC scales and numbers are red. The DC and DB (decibel) scales and numbers are black. Use the 0–300 range, and divide the reading by 100 for a 0–3-volt DC measurement. The AC scale

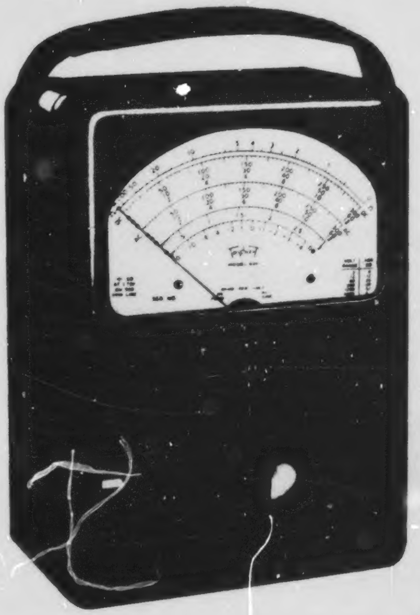
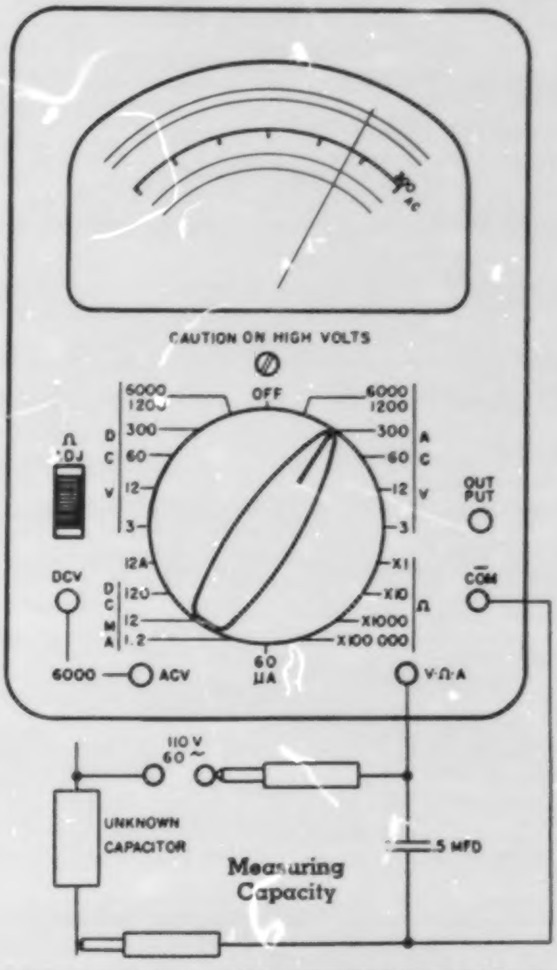


Fig. 8. Type of multimeter: the Triplet 630


AC
CAUTION ON HIGH VOLTS
OFF
6000
1200
300
60
12
3
D C V
A C V
Ω ADJ
12A
120
12
1.2
D C M A
X1
X10
X1000
X100 000
Ω
OUT PUT
COM
DCV
6000
ACV
60 µA
V·Ω·A
110 V 60 ~
UNKNOWN CAPACITOR
.5 MFD
Measuring Capacity

To Measure MFD	Set Selector Switch to	Deflection in AC Volts
.002	3 ACV	.45
.004		.83
.006		1.25
.008		1.65
.010		2.10
.020	12 ACV	4.3
.04		7.7
.05		9.7
.08	60 ACV	14.5
.10		17.5
.2		30.0
.4		45.0
.6		57.0
.8	300 ACV	65.0
1.0		75.0
2.0		85.0
5.0		95.0
10.0		100.0

CAUTION: Do not attempt to use this test on electrolytic condensers.

Fig. 9. Chart to determine the AC voltage range using the Triplet 630

has its own range of numbers on this particular meter. The large rotary switch in the center of the panel is used to select all functions and ranges. The markings are self-explanatory.

The Triplet 630 can be used to *measure capacity* by the arrangement shown. It is set up as an AC voltmeter. The chart in figure 9 may be used to determine the AC voltage range to use. Always start with the selector switch on the 300-volt range since, if the condenser is shorted, serious damage may result to the meter when it is on a low range.

The 630 also has some *special applications*. The unusually high ohmmeter permits some indication of condenser leakage resistance. Measure as a resistor, using the highest range. A good paper or mica condenser under 1 microfarad will indicate at the 100 megohms mark or above. If a steady reading (taken after the initial surge required to charge the condenser) of less than 100 megohms is obtained, the condenser probably has defective insulation. Good paper condensers over 1 microfarad may read somewhat less than 100 megohms. Electrolytic condensers should read above 0.1 megohm. In checking eletrolytic condensers, the black test lead ("com" jack) should be connected to the positive terminal of the condenser.

Checks of insulation resistance for motors, generators, telephone cables, power cables, and so on can be made on the high ohmmeter range of the 630. The actual value of resistance may vary from a few megohms to over 100, depending on weather conditions and quality of insulation. The best method, therefore, is to make periodic checks on important cables or equipment and observe the trend in readings. As the readings tend to be lower and lower, it is time to start drying out the equipment or determine the cause of deterioration. Dirt, mica, or foreign matter can sometimes cause excessive damage.

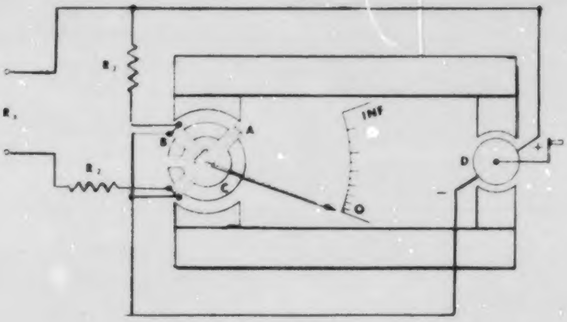


Fig. 10. Megger circuitry

Megger

An instrument particularly designed to measure high resistance is the megger (*mega* from Greek for million). The circuitry of a megger is shown in figure 10. The megger is used chiefly in measuring insulation values of such equipment as electric motor coils, high-voltage insulators for transmission lines, and so on. By being able to measure the resistance of the insulation of coils of motors, workers can often detect possible failures before they occur and prevent expensive shutdowns by replacing a motor when the megger indicates the resistance is below that recommended by the manufacturer.

The megger consists of a direct-reading ohmmeter and a hand-turned DC generator assembled together in a molded case. The resistance to be measured is connected to the two leads of the megger. When the small crank of the generator armature is turned, a pointer then indicates resistance value on a scale.

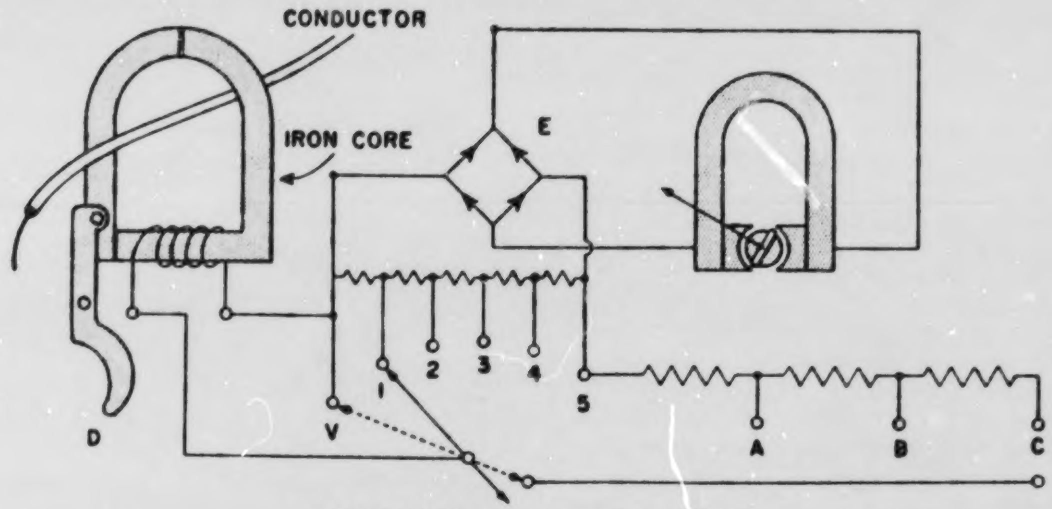
The ohmmeter of the megger has two coils—the potential coil and the current coil—which move together in the field of a permanent magnet. Within the air-gap of this magnet is a C-shaped permanent magnet, around which the coils pivot. Since there are no restraining springs for these coils, there is as little resistance to their rotation as possible.

When the meter is not in use, the pointer moves freely across the scale. When the meter is in operation, both coils develop torque, tending to turn the system in opposite directions. When the forces become equalized, the pointer comes to a stop, indicating the value of the resistance that is being measured.

When you want to measure very high resistance of insulation around the wires of a coil, connect one terminal of a megger to the outside of the insulator, the other terminal to the bare wire of the coil, and turn the small crank of the instrument at a sufficiently rapid rate to use the clutch to slip. When this slippage occurs, it means that the machine is maintaining the voltage value for which it is calibrated. The pointer will then indicate the resistance of the insulation in megohms. Most meggers are equipped with 500-, 1,000-, or 2,500-volt generators. Some meggers have two scales, one for low resistance and one for measuring extremely high resistance.

When making an insulation breakdown test with a megger, continue the test for at least a minute to see if the reading of the meter changes. If the windings are good, the resistance will increase because of capacity effect. If there is a slight leak, however, the resistance will remain constant. Insulation that shows perfectly good for low voltage, such as that produced by an ohmmeter, will sometimes break down under the high voltage of the megger. Two precautions to observe when using a megger are (1) to make sure the circuit being tested is disconnected from the power and deenergized and (2) not to use a megger to test something the high voltage might damage.

The megger is a portable device that generates its own electricity. Therefore, it is very necessary for jobs where electricity is not readily available. For shop and laboratory use, instruments are available that operate



THE HOOK-ON VOLT-AMMETER CIRCUIT

Fig. 11. The trigger (D) opens the jaws of the iron core that hooks around the conductor when current is to be measured. The iron core and its coil make up an instrument transformer with the conductor as the primary. On the right is a DC meter calibrated to read several ranges of current or voltage. The rectifier at E makes it possible to use this instrument for measuring AC. The voltmeter terminals shown at the lower right, with various resistances A, B, and C, are used to measure three ranges of voltages. The switch and connections, numbers 1 through 5, make use of shunts to give several current range readings.

on a 60-cycle, single-phase, 110-volt alternating current.

Hook-on Volt-Ammeter

A meter most often used is the "hook-on" type of electric meter. With this handy, portable instrument, a repairer can measure current flowing in a wire without interrupting service. When the laminated iron jaw of this meter is hooked over a wire and closed, a complete magnetic circuit is formed that concentrates the field of the conductor through this iron jaw, which, in effect, is the secondary of a current transformer. This secondary current is proportional to the current in the line.

Because of its sensitivity, a permanent-magnet type of meter is used to measure the "secondary" current. However, since this meter cannot be used to measure alternating current, rectifiers are placed in the secondary circuit of the hook-on volt-ammeter to provide "full-wave" rectification of the alternating current. To make a current measurement, the open jaws of the hook-on volt-ammeter are placed against the conductor (see figs. 11 and 12). A slight push on the instrument snaps the jaws shut, and the current flowing through the conductor will be indicated on the scale of the meter. A selector switch on the instrument provides access to different scales. The scale selected must be ample for measuring the current that will flow through the meter. Otherwise, it will be damaged. Also, remember to measure current in only one wire at a time.

In three-phase circuits, the three conductors are often contained in a single cable from the control to the motor. Hooking this meter aound this cable containing three conductors would result in a zero reading because the current in one wire is equal to, and opposite in direction to, the sum of the curents in the other two wires. Hook-on ammeters are usually provided with voltmeter leads so that voltage across a motor or other load can be measured. For voltage readings, the selector switch is set to the desired scale, and the voltage leads are connected to the terminals of the load.

If the current is too low for the meter to measure, you can make one or more loops out of the wire and clamp the meter through the coil. The more loops the coil has in it, the less current it takes to make the meter read full scale. For example, if a meter normally read 100 amp full scale, it could be made to measure 10 amp full scale by clamping it through a coil that had 10 loops.

Test Lights

Motor repair shops also use test lights to locate troubles and check to see if proper connections have been made (see fig. 13). These test lights are usually regular light bulbs in series with the power and two test leads. Sometimes extra low wattage bulbs are used where no power is needed in the test. If a small amount of power is needed, large bulbs or more than one in parallel can be used to provide the necessary power and still protect the circuit from too much current. If light bulbs are to be connected to a higher voltage, they are connected in series.

A good, portable, self-powered test light can be made by drilling a hole in the end of a flashlight and connecting a wire of the desired length to each side of the switch so that when the other ends are shorted together, the light will light. This test light works well on low-resistance circuits.

A test light that receives its power from the circuit being tested can be made by connecting a half-watt, half-megohm resistor in series with a small neon bulb. A suitable case for the bulb and resistor is an old fountain pen with the beads coming out one end and the other end made of clear plastic or having several small holes to emit the light. It will not work on voltages much lower than 90 volts, but it will work well on voltages up to 500 volts AC or DC. By increasing the value of the resistor, it will work on higher voltages. It can also be used to determine whether the voltage is AC or DC and to determine the polarity of DC.

The Growler

Another piece of test equipment is the growler (fig. 14), which is simply an AC electromagnet. It acts as the primary of a transformer, and the armature or winding being tested acts as the secondary. The growler is very simple to make. The size of wire, number of turns, and size of the core can be varied over a reasonably wide range without serious effects. Meters or lights are sometimes included for better and easier testing. Detailed plans can be found in many electrical books.

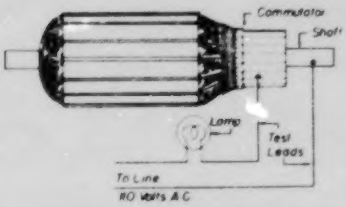
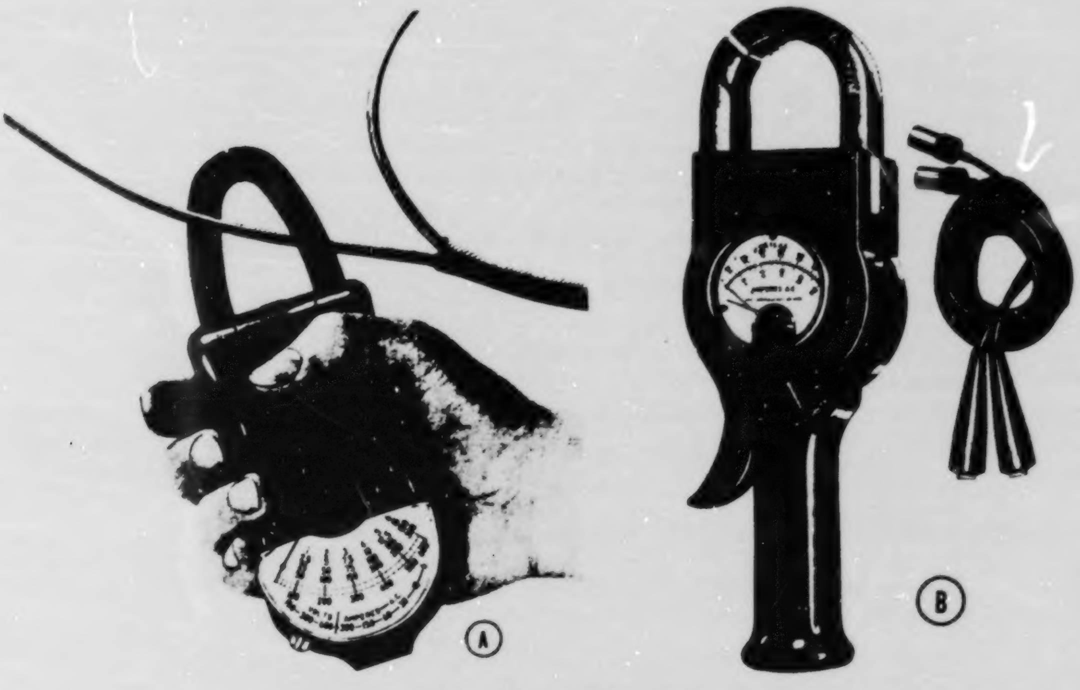


Fig. 13. Testing the completed armature for grounds after the leads have been connected to the commutator.

Prony Brake Horsepower Test

The horsepower output of a motor can be tested with a device called a Prony brake, an ammeter, a tachometer, and small scales. The Prony brake consists of two hardwood blocks shaped to fit a pulley on the motor shaft and attached to an arm so they can be adjusted closer together or farther apart. The arm usually makes contact with the scales exactly 1 foot from the center of the motor shaft, but it may be any desired length. Place the blocks on each side of the pulley, and adjust the arm so that it is level and making contact with the scales. Note the pressure on the scales with just the weight of the arm pressing on it.

Start the motor, and tighten the blocks gradually until the motor is drawing the amount of current indicated on its nampelate at full-load current. Measure the speed of the motor with the tachometer, and note the additional pressure on the scales. Then multiply this pressure, the distance in feet from the center of the motor shaft to the contact with the scales, the rpm of the motor, and 6.2832 together, and divide the product by 33,000. This will give you the



HOOK-ON VOLT-AMMETER

Fig. 12. At A is a compact hook-on volt-ammeter used to measure current up to 300 amp and up to 600 volts in an AC circuit. At B is a larger, heavy-duty, hook-on volt-ammeter with voltmeter leads shown at the right. When current is measured, the jaws are snapped around one line only. When voltage is to be measured, leads are plugged into the appropriate range plug and the leads connected across the line.

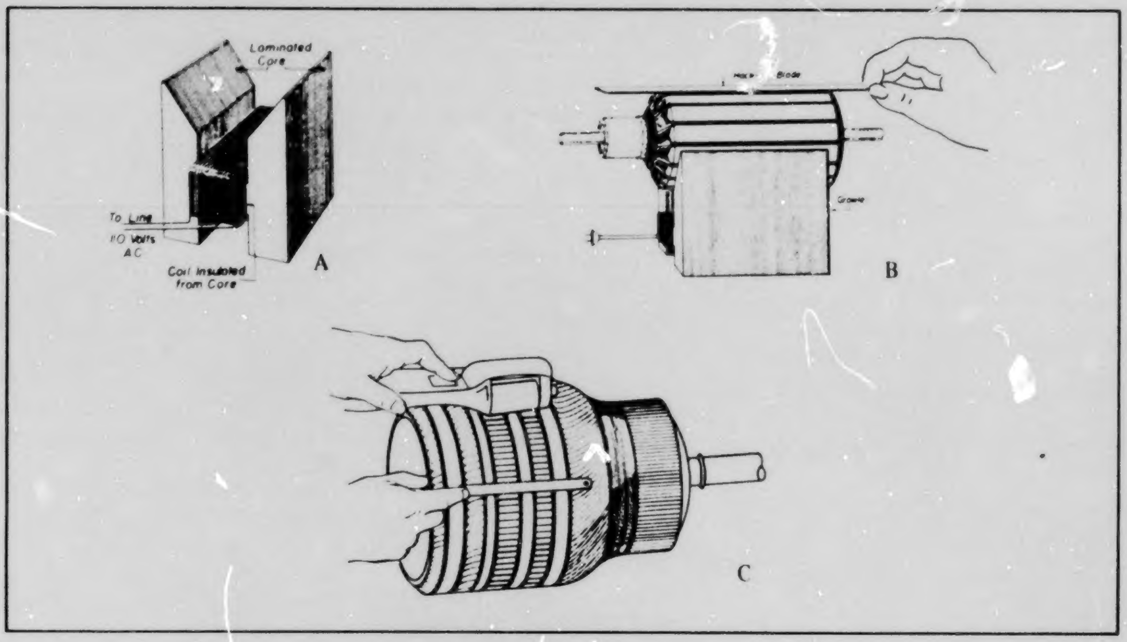


Fig. 14. A shows a growler consisting of a laminated core on which a coil of wire is wound; B shows an armature being tested for shorts by placing a hacksaw blade over the top slot; and C shows an internal growler being used to locate shorted coils in an armature.

horsepower output of the motor at full load, which should be the same as that indicated on the nameplate.

Exercise

1. How are voltmeters always connected in relation to the load?
2. How are ammeters always connected in relation to the load?
3. What might result if you touch the metal parts of the test leads or the circuit when using the high ohms range of a meter?
4. How may the range of a voltmeter be exceeded?
5. Before using an ohmmeter, where must the power be disconnected?
6. To safely use the voltmeter, where should you start the measurement?
7. What does the DC voltmeter measure?
8. How are fields supplied in permanent-magnet meters?

Section

J

Heating and Lighting

J-1. Heating Effects
J-2. Lighting Effects
J-3. Incandescent Lighting
J-4. Fluorescent Lighting

Objectives: After completing this assignment, you will be able to—
1. name the three methods of producing heat from electricity;
2. name the methods of heat transference;
3. tell what affects the heat produced by induction heating;
4. define *joule;* and
5. tell how heat is measured.

J-1

Heating Effects

Most of the electrical appliances in our homes depend on the heating effects of the electric heater and electric current. The heater is made up of a few coils of high-resistance wire, which become red-hot when a current is allowed to flow through them. These coils are found in coffee makers, irons, and toasters, as well as in hair dryers and other home appliances.

Today, electricity allows us to produce heat in nearly any desirable form and to control this heat with extreme accuracy. This heat is produced from electricity in one of three ways—resistance, induction, and dielectric.

Resistance Heating

This is probably the most common method of producing heat from electrical energy. As electrical current flows through a resistance, the electrical energy changes to heat. This principle is used in most heating appliances, such as stoves, ovens, heat lamps, and electrical blankets. Arc welding is a form of resistance heating. The arc that is formed takes place through a column of vaporized metal. A very large current, flowing in a small area, melts the metal at the ends of the arc. Spot welding is another example. The electrodes are pressed against each side of the metals to be joined, and the combined high current and pressure fuses the metals together.

Heat can be transferred from a heated electrical element by one of three methods: conduction, convection, and radiation. The electric stove transfers heat to a pan by contact (conduction) with the stove elements. A soldering iron is another good example of *conduction* heating. The heat is conducted from the element to the copper tip and then to the metal to be soldered.

Convection is the second method of transferring heat. A medium such as air, gas, or liquid conveys heat to the desired location. The fan-type heater is one form of this type of heating. The air near the resistance element is heated, and the fan blows the heated air into the room.

Radiation is the third form of heat transfer. A heat lamp radiates heat energy.

Induction Heating

Electrical conductors in a changing magnetic field become heated due to inducted eddy currents. Eddy currents are set up when a rapidly changing magnetic field cuts through a metallic object. The high currents flowing inside the metal cause it to heat. Another way to view induction heating is to think of the metal as a shorted secondary winding of a transformer.

The amount of heat produced by induction heating depends on the strength of the field, the rate at which the field changes, the specific resistance of the metal being heated, the area of the metal, and its position with respect to the magnetic field.

Dielectric Heating

If you bend a piece of wire back and forth until it breaks and then touch the point where the wire breaks, you feel heat. The heat is caused by the stress placed on the metal by the bending action. A stress is also produced when a dielectric (insulator) is placed between oppositely charged plates. This stress produces heat.

The dielectric process is used in the manufacture of some plywoods. The separate sheets of plywood, with glue between them, are placed between metal plates, and a rapidly changing charge is applied to the plates. The stress on the wood produces heat to cure the glue.

Mechanical Equivalent of Heat

Heat is measured in calories or in British thermal units (Btu). A *calorie* is defined as the amount of energy required to raise the temperature 1 gram of water by 1 degree centigrade. The *Btu* is defined as the amount of energy required to raise the temperature of 1 pound of water by 1 degree Fahrenheit.

In electrical terms, the *joule* is a unit of work equal to one watt-second. One calorie is equal to 0.239 joule, and one joule is equal to 4.185 calories. One Btu is equal to 252 calories. Expressing these terms as formulas:

$\text{Joules} = Pt = I^2Rt$
$\text{Heat} = I^2Rt$ joules
$= 4.185\ I^2Rt$ calories

when P is the power in watts, I is the current in amperes, R is the resistance in ohms, and t is the time in seconds. Therefore, the heat generated in a conductor is porportional to the time, the resistance, and the square of the current.

Heat can be produced in many ways. However, the production of heat by electricity is the most versatile and the most easily controlled method. From the formula, $J = I^2Rt$, we can see that the amount of heat can be controlled by changing the voltage, the current, the resistance, or the time.

Energy Relations of an Electric Current

Power (rate of doing work) is the product of the voltage drop between the ends of a conductor and the current strength. If the voltage drop (potential difference) is expressed in volts and the current in amperes, the power is given in watts:

watts = volts × amperes

The energy of our electric current is usually measured in kilowatt-hours. One *kilowatt-hour* (kwh) is the amount of energy produced in one hour by a current with a power of one kilowatt (1,000 watts).

Exercise

1. Name the three methods of producing heat from electricity.
2. What are heating coils made of?
3. How can heat be transferred from a heated electrical element?
4. What causes electrical conductors in a changing magnetic field to become heated?
5. Define the electrical term *joule*.
6. How is the energy of an electric current usually measured?
7. What is heat measured in?
8. How many calories are in one Btu?
9. What is the heat generated in a conductor proportional to?
10. What does the amount of heat produced by induction heating depend on?

Objectives: After completing this assignment, you will be able to—
1. discuss the incandescent lamp;
2. discuss the fluorescent lamp; and
3. discuss the panelescent lamp.

J-2

Lighting Effects

Some scientists believe that as much as 85 percent of all learning takes place through the eye, and, of course, the eye cannot function without light. Light can and does change the appearance of an object in space. It can affect a person's moods. Soft light is soothing, reasonably bright light is stimulating, and glaring light is disturbing.

Modern artificial lighting started with Edison's invention of the incandescent lamp in 1879. Modern electric lighting appropriate for home use is of three main types: incandescent lamps, fluorescent lamps, and panelescent lamps.

Incandescent Lamps

The incandescent lamp is still the most commonly used lamp. It gives a steady light without the flicker noticed in a single fluorescent tube. The original cost of fixtures is relatively low, and bulbs are quite economical. Bulbs come in a variety of sizes and shapes to suit a particular need or to please the eye. The disadvantage of incandescent lighting is that most of the electricity consumed is changed into heat, and only a small percentage is converted into light.

Fluorescent Lamps

The fluorescent lamp is the second most commonly used lamp in the home. For the same amount of electricity consumed, it produces about three times as much light as the incandescent lamp. For instance, a 20-watt fluorescent lamp will produce about the same amount of light as a 60-watt incandescent lamp. Since it also produces less heat, fluorescent lighting is especially good where a relatively large amount of light is needed. Much of the flicker or stroboscopic effect of the single-tube lamp has been overcome by using two or more tubes in one fixture. The cost of installation is generaly higher than for the incandescent lamp.

Cold-cathode lights are of tube construction similar to fluorescent lamps. They are used where extremely long life is a major consideration.

An important development in lighting construction is the germicidal tube, which gives off ultraviolet radiation. The bactericidal action of these rays is quite effective against airborne bacteria.

Panelescent Lamps

The panelescent lamp most generally found in the home is the night light. However, panels are now being made that are 2 feet by 4 feet. The panelescent lamp is flat. Some models are only 0.022 inch thick, but the more common model is 0.045 inch thick.

The life of the panelescent lamp is about 20,000 hours (120 volts and 60 hertz), at which time the illumination has been reduced nearly 50 percent. The amount of electricity converted into light is high, but at the present stage of development the brilliance is too low for much home use. The initial cost is quite high, but this could be offset by its long life and efficiency. As the brilliance of this lamp is improved, it will undoubtedly find wider usage, and the day will probably come when we will have luminous ceilings and walls.

Exercise

1. What is the most commonly used lamp today?
2. Which lamp produces about three times as much light as the incandescent lamp for the same amount of electricity?
3. What tube gives off ultraviolet radiation?
4. What lamp is generally used as a night light?
5. What is the advantage of incandescent lamps?
6. What is the primary disadvantage of incandescent lamps?
7. What is the advantage of cold-cathode lighting?
8. What is the disadvantage of panelescent lamps?

J-3

Incandescent Lighting

Objectives: After completing this assignment, you will be able to—

1. discuss the development of efficient electric lighting;
2. discuss how light intensity and amount are measured; and
3. define *reflectance*.

The incandescent lamp marked the beginning of efficient electric lighting. Since that time, the lumens-per-watt efficiency has been steadily increasing, while the cost has decreased. The following shows this progress:

1879—Edison's first commercial lamp, carbon filament, 1.4 lumens per watt
1893—Carbonized cellulose filament, 3.3 lumens per watt
1905—Metallized carbon, 4 lumens per watt
1906—Osmium and tantalum, 4.8 lumens per watt
1907—Pressed or squirted tungsten, 7.9 lumens per watt
1911—Mazda drawn-tungsten, 7.9 lumens per watt
1915—500-, 300-, 200-, 100-watt sizes, 12.6 lumens per watt

Today, the larger incandescent lamps have an efficiency of more than 26 lumens per watt.

The early development of more efficient lamps created a new problem—increased glare. The first attempt to overcome glare was by diffusing (reflecting) the light. Unfortunately, much of the light was also lost. Later, the undesirable glare was reduced, without any loss of light, by frosting the inside of the lamp bulb.

Incandescent lamps range from the 0.2-watt "grain of wheat" lamp used by surgeons to the 50,000-watt Mazda made by General Electric for movie production. The bulbs (glass envelopes) come in a variety of types, such as PS, F, G, S, P, A, C, and T. These code letters refer to the shape of the bulb. Numbers are added to the letters to indicate the diameter of the bulb in eighths of an inch. For example, *T-12* is a tubular bulb 1½ inches in diameter.

Lamp bases for Edison (screw-base) lamps are made in several types, such as miniature, candelabra, medium, admedium, mogul, and three-way light.

The *reflectance*, or reflection factor, is the percentage of light reflected from a surface. Reflectance may vary from 7 percent for certain dark green materials to 87 percent for certain white materials. The light not reflected is absorbed by the surface of the reflector.

Illumination Units and Terms

Photometry refers to the measurement of the intensity of light. Light, which is a form of radiant energy, is evaluated according to its capacity to produce visual sensation. The amount of illumination is a measure of the density of light falling on a surface. When light strikes a surface, the surface is illuminated.

The intensity of a light source is measured in *candlepower* (cp). The amount of light we receive from a light source depends on the intensity of the source and our distance from that source. This amount is measured in footcandles. One *footcandle* is the amount of illumination received from a source of 1 candlepower (one standard candle) on a surface that is 1 foot from and at right angles to the source. This means that a person seated 1 foot from a 30-candlepower lamp receives 30 footcandles of light. If a person is sitting 2 feet from such a lamp, however, that person receives only 7½ footcandles. The reason is that the amount of light an object receives is inversely proportional to the square of its distance from the source of light.

$$\text{Illumination} = \frac{cp}{d^2} = \frac{30}{2^2} = 7.5 \text{ footcandles}$$

where *cp* is the intensity of the light source in candles and *d* is the distance in feet from the source to the object.

The amount of light falling on a given point is measured with a light meter. A light meter is usually calibrated to provide camera exposure settings. A light meter can also be calibrated to measure the amount of light falling on a work area, in which case the meter is calibrated in candlepower or lumens.

The *lumen* is the unit for measuring light quantity, that is, the total amount of light actually given off by a source. If we place a standard candle at the center of a sphere of 1-foot radius, the amount of light falling on 1 square foot of the inner surface of the sphere will be 1 lumen. The inner surface area of such a sphere is 12.57 square feet. Since candlepower would be distributed over that area, you can see that 1 candlepower is equal to 12.57 lumens. The output of Mazda filament is rated in lumens. For example, a 100-watt lamp is rated at 1,620 lumens, and a 1,000-watt lamp at 21,000 lumens. A 40-watt, white fluorescent lamp is rated at 2,320 lumens.

Exercise

1. What lamp marked the beginning of efficient electric lighting?
2. What is *reflectance*?
3. What term is used to identify the intensity of a light source?
4. What was the first attempt to overcome glare in light bulbs?
5. Name the types of lamp bases for Edison lamps.
6. What device is used to measure the amount of light falling on a given point?
7. What is the unit for measuring light quantity?
8. How is the undesirable glare of a light bulb reduced?
9. What is the efficiency rating of large incandescent lamps?

J-4

Fluorescent Lighting

Objectives: After completing this assignment, you will be able to—

1. discuss the cost effectiveness of fluorescent lighting;
2. discuss the "start" procedure of the fluorescent tube;
3. name the types of starting switches;
4. discuss lamp life; and
5. discuss mercury lamps.

The development of the fluorescent lamp in 1938 opened up a new era in lighting that was as revolutionary and far-reaching as Edison's incandescent lamp in 1879. Each major development in lighting has been characterized by one all-important feature—more light. Fluorescent lighting has contributed to better artificial light in homes, offices, factories, and hospitals, where people rely on artificial lighting for safe and effortless seeing.

A fluorescent lamp operates at less than 40 percent of the cost of operating a tungsten lamp of equivalent candlepower.

Fluorescent lamps are available in four distinct types, depending on the operating circuit: (1) hot-cathode, preheat-starting; (2) hot-cathode, instant-starting; (3) cold-cathode, and (4) the "rf" lamp, which operates from radio-frequency energy.

The fluorescent lamp consists of a glass tube 1 to 1½ inches in diameter and 18 inches or more in length, fitted into a special socket. The inside of the tube is coated with chemicals known as *phosphors*, which glow when exposed to ultraviolet light.

When operating with AC, the fluorescent light actually goes out 120 times each second. This flicker is usually not noticeable. However, it may be noticeable as a stroboscopic effect when a moving object comes into view. To minimize flicker, lamps may be operated in pairs on two-phase circuits or in sets of three on three-phase circuits. When only single-phase circuits are available, a two-lamp ballast can be used for hot-cathode or cold-cathode lamps. This ballast supplies leading current to one lamp and lagging current to the other. The phase difference is such that the light pulsations of the two lamps compensate each other and eliminate the flicker.

Fluorescent lamps may be operated on DC if a resistance is added to the ballast in order to limit the operating current to the designed value. However, lamps more than a few feet long, when operated from DC, will accumulate mercury vapor at the negative end. As a result, only part of the bulb will give off light. This fault can be overcome by reversing the polarity of the lines feeding the lamps or by periodically turning the lamp end for end in the sockets.

Hot-Cathode, Preheat-Starting Lamps

Before a fluorescent lamp will "start," it requires a momentary voltage higher than the line voltage in order to establish the arc discharge through the gas inside the tube. This is done by adding an inductance coil or choke coil (a fluorescent lamp ballast) in series with one side of the line.

Figure 1 shows two circuits in which ballast coils are used. When the starter is in its closed position, current flows from the line, through the ballast, the cathode, the starter, the second cathode, and back to the line. The current heats the cathodes. When the starter opens, the inductive surge from the ballast strikes an arc between the heated cathodes.

Figure 2 shows a cross-section view of a hot-cathode, preheat-starting lamp and the three steps of its operation. In step 1, an electron emitted by the electrode at one end of the tube travels at high speed through the tube until it collides with one electron of the mercury atom. In step 2, the impact diverts the mercury atom electron out of its orbit. When it snaps back into place, ultraviolet radiations are produced. In step 3, when the ultraviolet rays reach the phosphor crystal, the impulse travels to one of the active centers in the crystal. Here an action similar to that in step 2 takes place—except that this time visible light is produced.

Figure 3 shows the starting and operating circuits. One terminal from each end of the lamp is connected to the operating circuit, and the other terminals (pins) are connected to the starting circuit. The cathodes are preheated for a short time to start the lamp. An arc is struck because of the inductive surge of current as the starting circuit is opened.

Hot-Cathode, Instant-Starting Lamps

One type of hot-cathode, instant-starting, fluorescent lamp looks like the preheat-starting lamp. Another type has only a single-pin connection

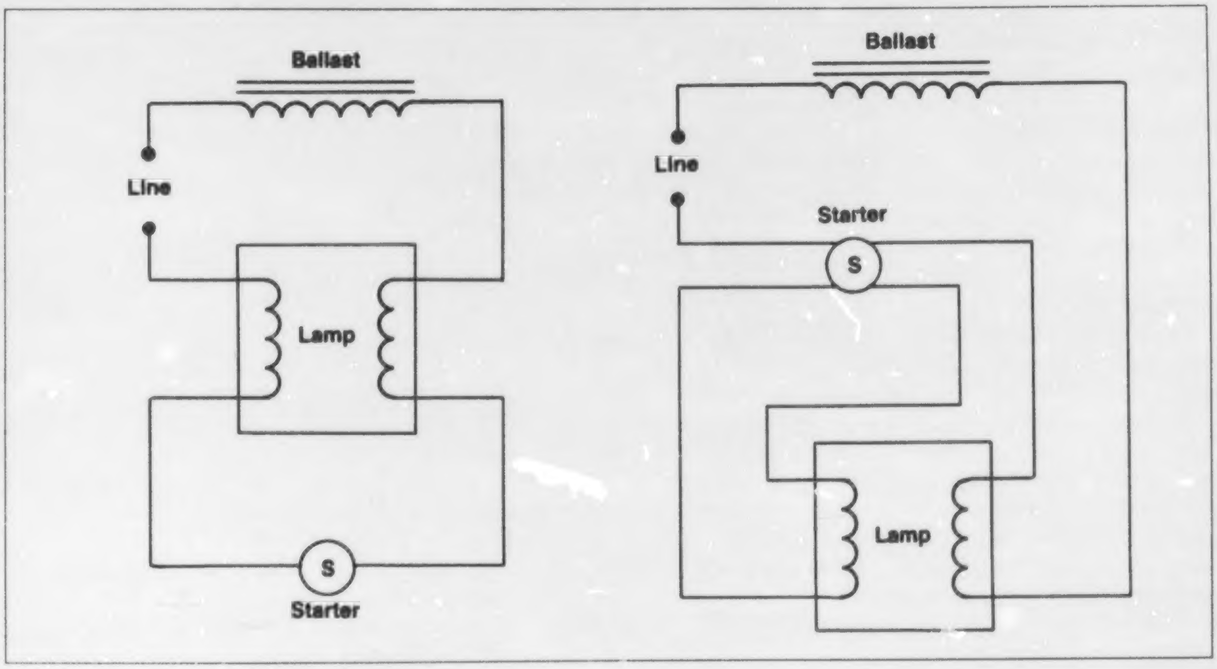

Ballast
Line
Lamp
S
Starter
Ballast
Line
Starter
S
Lamp

Fig. 1. Fluorescent lamp operation using ballasts

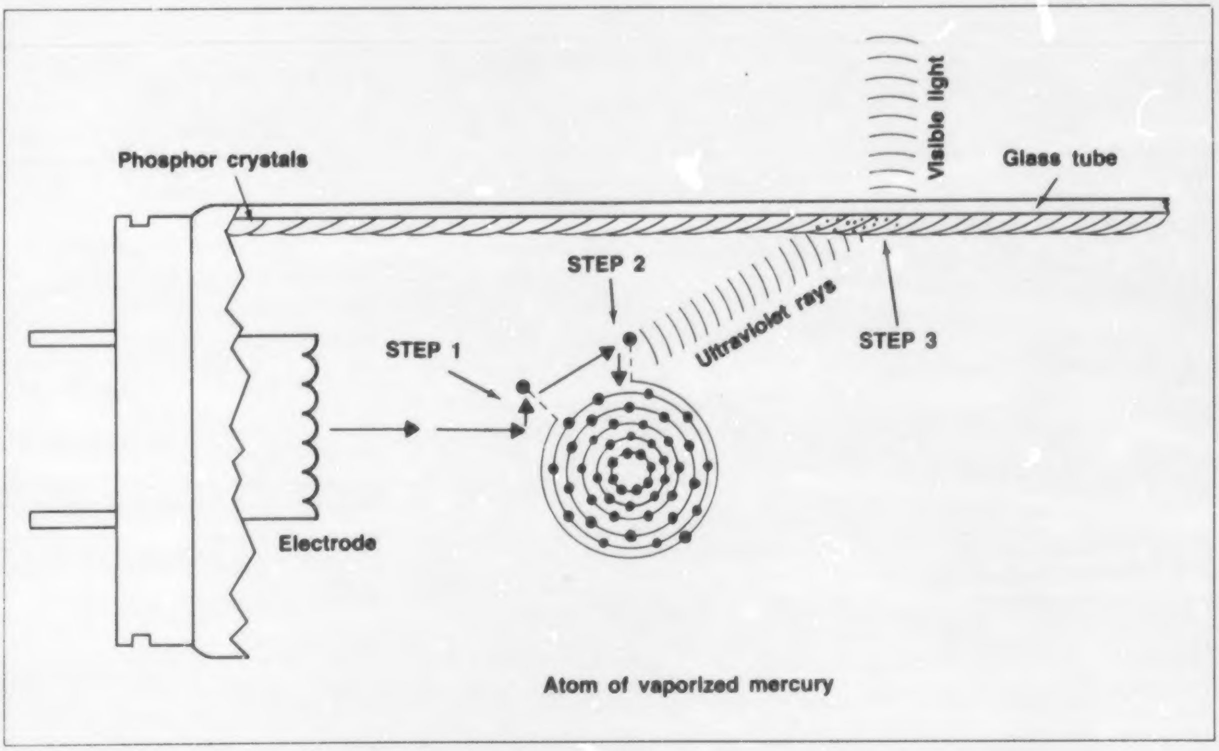

Visible light
Phosphor crystals
Glass tube
STEP 2
Ultraviolet rays
STEP 1
STEP 3
Electrode
Atom of vaporized mercury

Fig. 2. Three-step operation of a hot-cathode, preheat-starting lamp

at each end. When there is a two-pin base at each end, the two pins are short-circuited internally and act like a single pin. The other difference between instant-starting and preheat-starting lamps is in the cathodes. The instant-starting cathode must withstand the shock of a high-voltage arc striking between cold cathodes. After the arc is struck, a cathode flow is produced, and the lamp operates like a preheat-starting lamp.

Instant-starting lamps are started by applying a voltage between the cathodes that is high enough to "break down" the gas and start the arc. Lamps of this type require starting voltages of 450 to 750 volts. Because of the high voltage, electrical codes require the lamp holders to be wired so that the primary circuit will automatically turn off when a lamp is removed.

The preheat-starting lamps for two-pin lamps require a starter for each lamp. Only one of the holders will have a starter socket. A typical holder for single-pin lamps is shown in figure 4. One holder is used for the high-voltage end of the lamp, and the other for the low-voltage end.

Starting Switches

Starting switches are available in three main types: manual, glow-switch, and thermal.

The **manual** starter is hand-operated. The preheating period is controlled by the operator. A push-button switch is usually depressed until a glow appears at the ends of the tubes. An inductive surge strikes an arc through the tube (bulb) when the push button is released.

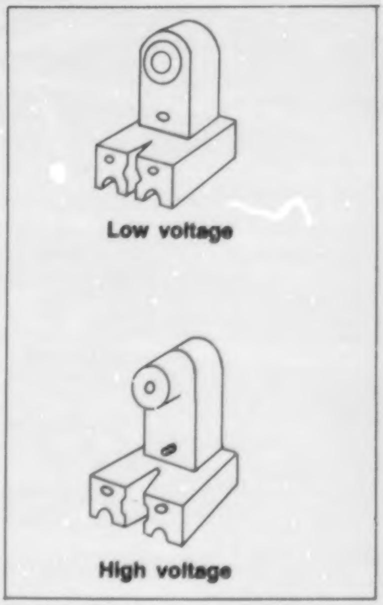


Fig. 4. Holders for single-pin lamps

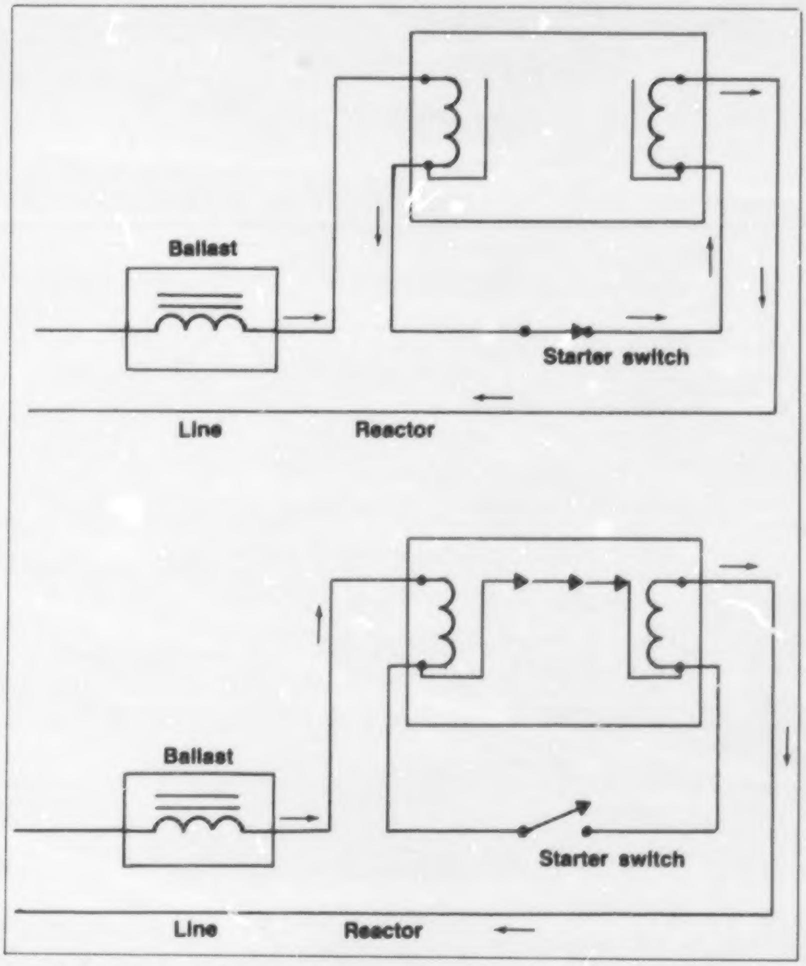


Fig. 3. Starting and operating circuits of a hot-cathode, preheat-starting lamp

The **glow-switch** starter is essentially a glow-lamp in which one of the electrodes is a bimetallic, thermostatic blade. When the lamp is energized, the glow discharge around the electrodes releases enough heat to cause the bimetallic blade to warp, thereby touching the other electrode of the glow-lamp. This contact is, in effect, a switch that closes the starting circuit and permits the preheating current to flow until the contact is cooled. When the contact is broken, the starting circuit is opened.

The **thermal** starter includes a resistive element that carries a filament current and is, in turn, heated by this filament current. The heater element warms a bimetallic, thermostatic blade. This causes the blade to warp, thus opening the filament connection after the filaments have been warmed enough to glow. After the arc is struck in the tube (lamp), the operating current that flows through the heater holds the starter switch contacts in the open position.

Cold-Cathode Lamps

Cold-cathode lighting is often associated with neon lighting. However, cold-cathode lamps are more difficult, and more time-consuming, to manufacture than neon fixtures. Both cold-

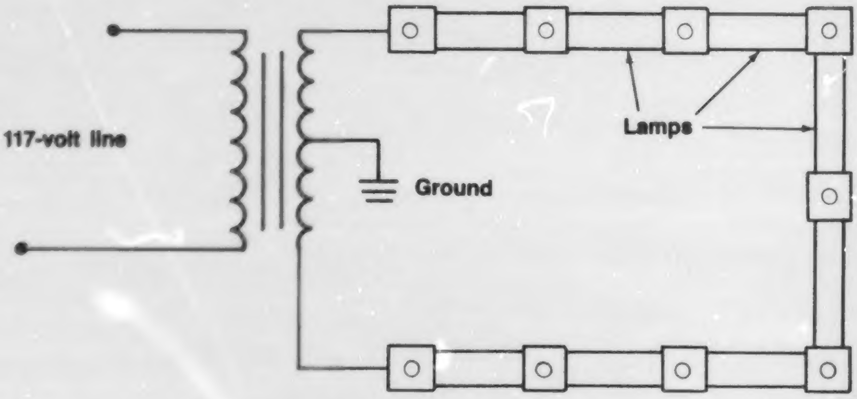


Fig. 5. Series operation of cold-cathode lamps

cathode tubing and neon tubing can be bent into letters and outlines.

Cold-cathode fixtures are available in many sizes and shapes. The four-lamp, 8-foot room fixture may be connected to a standard 110-volt AC outlet. It has a self-contained ballast that automatically steps up the 110 volts in order to start the lamp. Custom installations can be recessed, with the lamps placed in coves or above a luminous ceiling. A remote high-voltage transformer is used, with its leads running into the cove or ceiling where the lamps are located. The cold-cathode fluorescent lamp furnishes high-quality lighting at low-operating and maintenance cost.

The gas pressure of a cold-cathode lamp is higher than that of a hot-cathode lamp. The cathodes are hollow cylinders of pure iron, coated on the inside with one of the active oxides of certain alkaline earths (such as barium and calcium).

Cold-cathode lamps are instant-starting. They can be used in either multiple-circuit or series applications. For series operation, the lamps are connected in series, as shown in figure 5, and operated from a ballast or from a transformer with a high secondary voltage. Depending on the number of lamps in series, the ballast voltage may range from 2,000 to 15,000 volts, and the lamp operating currents from 12 to 100 milliamperes.

Lamp Life

Fluorescent lamp life is influenced to a great degree by operating conditions. For example, operation with frequent starts shortens lamp life appreciably. On the other hand, operations with many burning hours per start lengthens lamp life. For this reason, lamps have several different life ratings, based on the number of hours per start.

The curve in figure 6 shows the burnout percentage of fluorescent lamps, plotted against percentage of rated lamp life. This curve is valid for all popular fluorescent lamps, under most operating conditions. Average life ratings for the various lamps and operating conditions can be obtained from manufacturers' data sheets.

Like other types of lamps, fluorescent lamps depreciate in light output as they age. The initial light output is variable from lamp to lamp, and this value may decrease rapidly during the first 100 hours of operation. The lumen depreciation may amount to as much as 10 percent. For rating purposes, the 100-hour value is used as the initial value.

The curve in figure 7 shows the typical range of fluorescent lamp depreciation in light output versus time. The vast majority of lamp types depreciate along a line near the upper limit of the curve. Light depreciation is not noticeably affected by the number of burning hours per start.

Mercury Lamps

Mercury lamps combine the relatively small size of incandescent lamps with the long life and high efficiency of fluorescent lamps. These high-wattage light sources produce a considerable amount of light for their size. As a result, mercury lamps offer many advantages to the user, particularly in industrial lighting, street lighting,

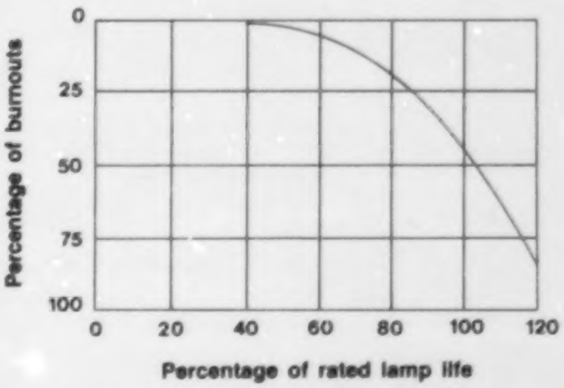


Fig. 6. Percentage of burnout of fluorescent lamps

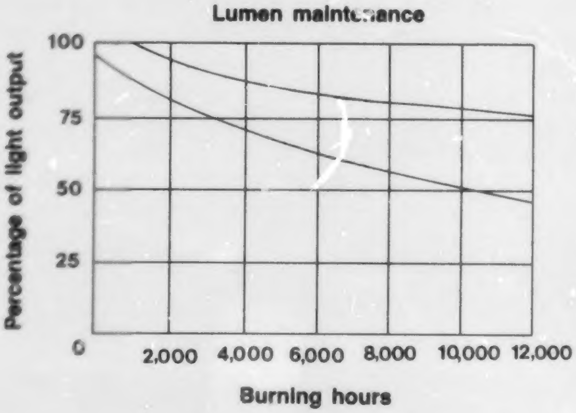


Fig. 7. Light output versus burning time

floodlighting, and other outdoor commercial applications. Mercury lamps are electric discharge lamps. As such, they produce light by passing a current through a gas vapor under pressure, rather than by heating a filament as in incandescent lamps.

Although the first high-pressure mercury lamp was not introduced until 1934, the first mercury vapor lamp was developed in 1901 by Peter Cooper Hewitt. Known as the Cooper Hewitt lamp, it was about 4 feet long and produced bluish-green light. The mercury lamp, as it is known today, was first introduced in the 400-watt size with a glass arc tube. Later, other lamps were added, and now general lighting mercury lamps range from 100 to 3,000 watts.

In recent years, several significant improvements in mercury lamp performance have been introduced. The development of color-improvement and white phosphor-coated lamps added versatility in light output and color rendition with mercury lamps. Today's 400-watt clear mercury lamp is rated at 20,500 lumens, with an average life in excess of 16,000 hours and 92 percent lumens over 16,000 hours. A few years ago, a 400-watt clear lamp was rated at 20,000 lumens, with 3,000 hours of life at 83 percent lumens over 3,000 hours.

Figure 8 shows the basic parts of the mercury lamp. Nearly all mercury lamps consist of an arc tube enclosed within an outer tube, plus supplementary parts. The arc tube contains the essential operating parts—electrodes, mercury vapor, and argon gas. The outer bulb maintains nearly constant arc tube temperature, and protects the arc tube and internal parts from the atmosphere.

The initial light output rating of mercury lamps is based on the average light output after 100 hours of operation. Lamps are rated for operation in a vertical position. Operating a mercury lamp in a horizontal position reduces the light output. In case of a power interruption or voltage drop for more than one cycle, mercury lamps extinguish and do not restart for several minutes. The exact magnitude of the voltage drop required to cause this condition depends on the ballast design.

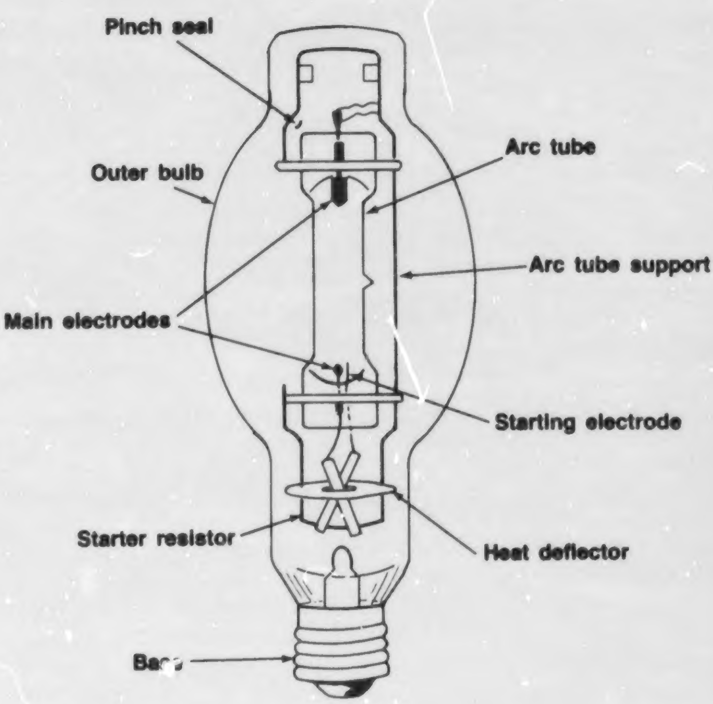


Fig. 8. Basic parts of the mercury lamp

Mercury lamps have operated on frequencies as low as 25 cycles with special ballasts, but lamp flicker is noticeable. Mercury lamps can operate on direct current, but special ballast circuits are required. Normally, the light output of mercury lamps is not affected by low temperatures or cold drafts. However, if an exposed lamp is subjected to low temperatures, it may not warm up. This depends on the fixture and ballast design. Once a lamp warms up, the outer bulb isolates the internal arc tube from the effect of outside conditions.

Exercise

1. What shock must the instant-starting cathode withstand?
2. What are the types of starting switches used for fluorescent lamps?
3. What influences the life of a fluorescent lamp?
4. What does the thermal starter include?
5. What is the purpose of the phospher coating on the inside of a fluorescent tube?
6. What is the purpose of a ballast or a ballast transformer in a fluorescent lamp?
7. What is the average life of all general lighting mercury lamps?
8. What is the intensity of illumination of a footcandle?
9. How does the operating cost of a fluorescent lamp compare with that of a tungsten lamp of equivalent candlepower?
10. How may fluorescent lamps be operated on direct current?
11. What is a glow-switch starter?
12. How do mercury lamps operate?
13. What is the initial light output rating of mercury lamps based on?

Section

K

Electric Appliances

K-1. Electric Ranges
K-2. Electric Clothes Washers
K-3. Electric Dishwashers
K-4. Electric Disposers

Objectives: After completing this assignment, you will be able to—

1. discuss the heating process of the electric range;
2. describe how a bimetal switch operates;
3. explain the operation of the oven thermostat; and
4. explain the use of circuit breakers.

K-1

Electric Ranges

Electric ranges, like gas models, have two separate sets of heaters—the surface units and the oven unit or units. Ovens are generally equipped with two units: (1) an overhead unit for "broil" and (2) an oven floor unit that is used along with the upper unit for "bake." Surface units and oven units have separate controls

Wiring Requirements

Until recently, most electric ranges had both a 110-volt and a 220-volt circuit. These were used together in various combinations to achieve the different degrees of heat required for cooking. Today, most ranges use only the 220-volt current controlled by a bimetal or bulb-type thermostatic switch that cycles the current on and off for shorter or longer periods to achieve the desired heat ranges.

Most electric ranges require 110/220-volt, three-wire, single-phase, 60-hertz alternating current. Ranges are usually rated at about 60 amperes capacity, but fused at 50 amp. The maximum amperage of the range may exceed its fuse capacity. However, since it is unlikely that all the range units will be turned on *high* at the same time, fusing is set at about 80 percent of the full amperage rating of the range. The consumer should be told about this to avoid the nuisance of a blown fuse or flipped circuit breaker.

Electric ranges cannot be used on a 220-volt, two-wire, single-phase system, nor on a 220-volt, three-wire, three-phase system. They cannot properly be operated on 110-volt, two-wire service because of voltage requirements. The 60-ampere capacity requires the use of a heavy No. 6 wire to carry the load of a high-wattage appliance such as the electric range.

The electric range is normally directly wired, meaning that no line cord is provided for plugging into an outlet. A heavy-duty, three-prong, grounded wall outlet may be provided if local electrical codes permit this type of installation.

Surface Units

Surface units may be of two types: (1) the older wire-coil type, which is similar to a hot plate with the wire coils exposed, or (2) the newer tubular units. In the newer units, a wire coil is contained in a magnesium alloy tube and isolated from the tube by porcelain or composition spacers through which the wire coil is threaded. The wire coils are made from specially treated alloys selected for their resistance to intense heat.

The wattage, or heat-producing capacity, of the surface unit is directly related to the number and size of the wire coils, which set up an ohmic resistance to the electrical current. Most ranges have three surface units of about 1,250 watts each and one larger unit of about 2,000 or 2,100 watts. The amount of heat produced by a unit is varied in one of two ways. The 110/220-volt coils are controlled by a switch where the settings may be changed to apply 110 or 220 volts, arranging the coils in series or in parallel. The other method uses 220 volts only, with an infinite heat switch.

The most recent method of achieving variation in heat for the surface units is by means of a bimetal switch, which is similar in principle to a thermostat. However, instead of being acted on by external heat, its own internal heat causes it to cycle on and off. Inside the switch (see fig. 1), bimetal strip *A* has electrical contact at one end, and the other end anchored in the body of the switch. As current passes through the bimetal strip, it tends to curl up and away from the contact at the end of another metal strip, *B*. This strip is spring-loaded so that it presses against a spiral cam surface actuated by a switch knob. Another set of contacts is opened manually whenever the knob is turned to *off*.

When the knob is rotated 45° clockwise, a sharp incline on the cam surface drives metal strip *B* up tightly against bimetal strip *A*, making a firm contact. In the ***high*** position the bimetal *A* cannot curl enough to break the contact. Thus, the surface unit is continuously on at ***high***. As the knob is rotated clockwise, the force of the spring presses strip *B* against bimetal strip *A*, so that it warms up and moves away from its contact with strip ***B***.

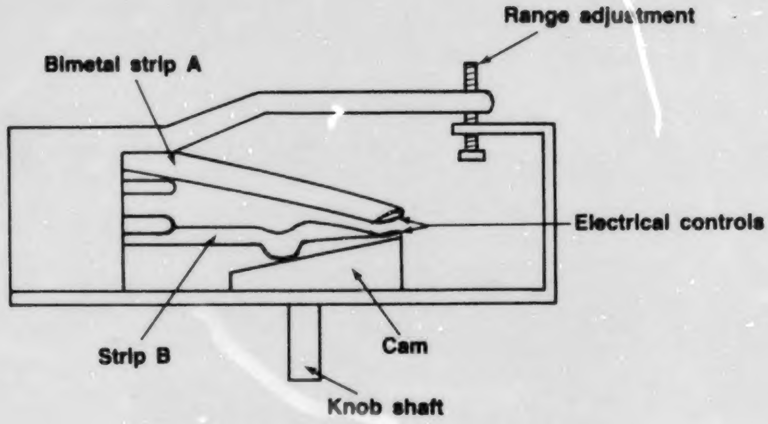


Fig. 1. Bimetal switch for surface unit heat

Since the cam surface is close to its highest point, bimetal strip *A* will not break contact until after a fairly long period.

The more the knob is turned clockwise (toward *low*), the shorter these *on* periods will be until, at *simmer*, the surface unit will cycle on for only about 20 to 60 seconds out of every 10-minute period.

The surface unit infinite heat switches may be calibrated for proper heat input. First, set a flat-bottomed saucepan partly filled with water on the unit to be checked. Turn the control knob to *low boil*, if such a setting exists, or to a point just below *high*. The water should come to a definite boil within a reasonable length of time, but it should not attain a vigorous, rolling boil.

Change the setting by removing the control knob to uncover a setscrew. The screw may be recessed so that it can be reached only through a hole in the body of the switch. If the water did not attain a definite boil in the test, increase the temperature by turning the setscrew counterclockwise. If the boil was too vigorous, decrease the temperature by turning the setscrew clockwise. If changing the setting of the screw does not affect the temperature, the switch is defective and should be replaced.

Oven Units

Modern electric ranges have two tubular oven units, a broil unit at the top of the oven and a bake unit at the bottom. The broil unit is made up of two coils, with a combined wattage of about 3,000 watts. The bake unit is a single coil with about 2,500 watts. When baking, the bake unit should glow red, and the broil unit should get hot, but not red. When the selector switch is set to *broil*, the broil unit should glow red too. In addition to the main oven, some ranges feature a second, smaller oven, which has a variety of trade names. It may have a smaller tubular unit, rated about 1,500 watts, which is used to prepare small, quick meals. Some ranges feature a second, separate oven of equal size, which permits baking and roasting at the same time.

Adjustment of oven tempeature requires two controls, a selector switch and a thermostat. The selector switch generally has three positions—*bake*, *broil*, and *off*. The *bake* position of the switch places the two coils of the broil unit in series, with resulting low wattage across the coils. In this position, the bake unit will glow red, but the broil unit will not. In the *broil* position, the switch places the two coils of the broil unit in parallel, with resulting high wattage causing the unit to glow red.

The thermostat is marked off in degrees of temperature. It causes both units to cycle off when the proper temperature setting is reached, and to cycle on again when the temperature falls below a preset lower limit.

Ovens generally have a bulb-and bellows-type thermostat, which is filled with a liquid. As the bulb senses more heat, the liquid expands slightly, pushing open a bronze collapsible bellows that works against the force of a spring to open a pair of electrical contacts. With the source of heat eliminated, the liquid contracts, and the bellows tends to collapse under the force of the spring until the contacts are remade.

Timers and Other Features

Timers may be provided for the oven unit only, or they may control each of the surface units as well. The timer is powered by a synchronous motor. It may also incorporate a clock as part of the assembly.

The timer assembly consists of a set of cam wheels, much like the timer on automatic clothes washers. A series of terminals opens and closes the appropriate circuits to surface units, ovens, or appliance outlets, as selected by the user.

Spring-power timers may also be found on earlier models of electric ranges. This is simply a clock mechanism which is wound and set at the same time by the control knob. When the winding runs out, a mechanical train forces open a pair of electrical contacts to open the circuit.

Electric ranges may be equipped with a thermostat that provides a cool-down period just before the end of an automatically preset cooking time. This would work in the same way as the system for gas ranges, except that electrical switches would be actuated instead of gas solenoid valves.

Ranges rated at 60 amperes and fused at the branch line with only 50-ampere fuses require an additional fusing arrangement at the range to eliminate the nuisance of blown branch line fuses caused by turning on all the units on *high*. This is usually accomplished by a circuit breaker, generally located on the control panel for easy access.

When the range wattage consumption exceeds the high limit set by the circuit breaker, threatening to blow the branch line fuse, the circuit breaker will snap open the contacts, shutting off all power to the range. The user should have been instructed to turn off all the units and reset the button on the circuit breaker. However, if the overload condition that caused the circuit breaker to open still persists, the breaker will not reset in the closed position.

Circuit breakers, as mentioned before, are energized when the force of a magnetic field created by a current exceeds the holding power of a spring-loaded mechanism.

Some ranges also have convenient outlets that provide 110-volt current for the operation of small appliances on or near the range.

Various other features, such as an electrically driven oven spit, glass doors, and deep-well cookers, are offered by range manufacturers. These are generally simple devices, easily traced through the wiring harness of the 110-volt circuits.

Exercise

1. What are the two types of surface units?
2. What is the wattage of the surface unit related to?
3. What is the most recent method of achieving variation in heat for surface units?
4. How does a bimetal switch operate?
5. What types of tubular oven units are used in modern electric ranges?
6. What two controls adjust oven temperature?
7. How does an oven thermostat control heat?
8. How does a timer work?
9. Why are circuit breakers installed on ranges?
10. When are circuit breakers energized?

K-2

Electric Clothes Washers

Objectives: After completing this assignment, you will be able to—

1. discuss the different types of clothes washers;
2. describe the major assemblies of clothes washers;
3. discuss the mangle;
4. discuss the water pump;
5. discuss the operation of the agitator; and
6. explain the function of the lid switch.

Modern washers can be divided roughly into two main types, automatic and conventional. The automatic type is further divided into tumbler and agitator. The conventional type is divided into wringer and twin-tub.

Automatic Washers

Tumbler Types. Tumbler washers are "front loading." That is, the clothes are placed in the washer through a door that opens to the front. Some models have the door on the circumference of the cylinder basket through which clothes are loaded and removed.

The cylinder basket of a tumbler washer rotates in a horizontal plane. That is, its axis is parallel to the floor. In some models the axis is inclined slightly, sloping to the rear. Agitation of the clothes occurs as they are lifted out of the soapy water by a rotating basket, and then fall back into the water of their own weight as they reach the top of the revolution.

The cylinder basket revolves slowly (about 50 rpm) during the wash and rinse periods, at the end of which the water is drained from the machine. The cylinder basket then revolves much faster (600 rpm) to spin the clothes damp dry and ready for final drying.

Because there is no agitator, construction of a tumbler washer is somewhat simpler. It only needs a means to spin the cylinder basket at two or three different speeds.

Agitator Washers. Agitator washers are loaded from the top. In this type, the axis of the cylinder basket is vertical to the floor, and the basket does not spin during the wash or agitation cycle. Instead, an agitator oscillates in the tub, sloshing the water and the clothes through an arc of about 180°. Some agitators have a vertical motion as well. Still others incline the plane of movement from the vertical, causing an undulating motion. These added motions are designed to create greater turbulence in the water for maximum loosening of dirt.

Operation of Automatic Washers. The automatic washing machine is probably the most complicated piece of machinery in the modern home. This is because it must perform a great many functions in the course of the complete washing cycle.

First, the operator selects the water temperature and the amount needed for the load. The maximum load of clothes should be about 8 to 15 pounds dry weight, although some manufacturers claim greater capacity for their washers. A detergent (and bleach or softeners, if desired) is added to the proper receptable or placed directly into the machine. Then a button is pushed or a dial is turned, causing the machine to take over and begin the washing.

The act of turning on the machine actually does no more than close circuits to the drive and timer motors. The drive motor in most machines is coupled to the agitator or the cylinder basket and a water pump. A secondary circuit in the electrical system feeds current to a timer motor that controls all the operations of the machine during the entire wash and spin cycles.

When the operator turns the various selector dials for the type of wash desired, a set of cams is aligned, presetting a switch and adjusting a pair of water inlet valves. If the machine offers a choice of either normal or gentle action, a different set of cam wheels is brought into play for the selection made. These cam wheels are revolved slowly by the timer motor. As they revolve, their surfaces make contact with switches at various points in their travel, opening and closing circuits to energize solenoids, and segments of circuits to activate or stop the various components in the system.

Most machines offer a choice of fill levels—high, medium, or low—depending on the amount of wash to be done. When the operator makes a fill selection, a pressure switch or a float switch is, in reality, being preset to open when the proper level is reached. In the same manner, selecting hot, warm, or cold wash water involves opening or closing the water inlet valves by means of solenoids.

The fill switch in most machines is in control throughout the operation, except that it is bypassed at the empty position during the brief spray rinses. With the fill switch in control, the agitator cannot function until the machine is filled with water to the proper level. Initially, then, when the operator pushes the start button, the water pump inlet valve is opened and water is admitted into the machine. If the operator selected a hot wash cycle, a solenoid is energized to open the hot water inlet, bypassing the cold water solenoid valve. The reverse happens for a cold wash. For a warm wash, both solenoids are energized. The water is cut off by the pressure or float switch when the proper level is reached.

In the meantime, the timer motor has been slowly revolving, rotating the cam wheels until finally a switch closes that completes the circuit to the transmission. The fill switch is still in control, however, and will not permit current to flow to energize the transmission until fill has been achieved. When the fill switch has been satisfied, current to the transmission now flows, and another solenoid is energized. This solenoid causes the drive clutch to engage, and the agitator begins to oscillate or the tumbler basket begins to revolve in the wash cycle.

Agitators and cylinder baskets (in tumbler washers) are driven through either a gear train or clutch arrangement. In an agitator, it is driven either by (1) a train consisting of a pinion gear, a drive gear, a connecting rod, and a sector gear or (2) a rack-and-pinion arrangement. These mechanical assemblies convert the rotary motion of the drive motor to an oscillating motion, driving the agitator through an arc of about 180° at 60 strokes per minute. In some agitator washers, the basket may wobble slightly during agitation, but it does not spin. However, during the spin cycle, the agitator is locked in with the basket so that both are turning. If the agitator did not turn during spin, the clothes would be in danger of being torn between the spinning basket and the stationary agitator.

After the agitation or wash cycle, a cam surface on the timer-motor cam assembly closes another switch, energizing a solenoid valve to open and drain the tub. In most washers, the water pump is constantly in operation during the entire wash and spin cycle so that it is only necessary to open and close various valves in the water system to achieve fill, drain, and spray rinses. During drain, all motion of the agitator or cylinder basket stops under the control of the fill switch, which will not permit resumption of drive until all the water is emptied from the tub.

A short spin cycle may follow, to remove any suds that may remain in the tub and the clothes. A spray rinse, in which a small amount of water is admitted briefly into the tub, helps this cycle along. During the spray cycle, the outlet valve remains open so that the water coming in drains out immediately.

The timer motor now advances another cam surface to close the switch controlling the water inlet valve. At the same time it opens the circuit to the drive solenoid, causing the basket to come to a stop. After a brief pause, the timer motor closes the fill switch, and the tub fills with water again. In some washers, this fill temperature may be preselected at the start from a dial that gives combinations of hot, warm, or cold wash with warm or cold rinses.

The deep-rinsing cycle is usually brief, accompanied by a short period of agitation. At its conclusion, all motion of the cylinder basket or agitator again comes to a stop, and the tub empties.

The washer now goes into the final rinse and spin-dry cycles. Final rinsing may consist of a spin, accompanied by one or two brief spray rinses. The purpose of these is to dislodge, through the holes in the cylinder basket, any residue of soap, scum, or dirt left on the clothes as the water level receded during the drain cycle. After the last spray rinse, the cylinder basket continues to spin at high speed for a few minutes, during which most of the water is driven out of the clothes by the centrifugal force of the spin.

Finally, the timer motor advances to a point where all circuits are opened, and the washer shuts itself off.

Conventional Washers

Conventional washers are relatively simple in operation. The user fills the tub by means of a hose connected to a nearby mixing faucet, adds soap, and turns the motor on. The user starts the agitation by throwing a clutch lever that engages a gear train similar to the one in an automatic washer. The agitator operates with an oscillating motion unitl the user decides the clothes have washed long enough. The user then disengages the agitator clutch lever and turns the hand-operated drain valve to *drain*.

It is important to understand why the agitator must stop during drain. If it were to continue operating without water in the tub, the effort of pushing against the weight of the clothes would probably cause a motor overload. Also, the clothes themselves might become mangled in the process.

Draining is done in a conventional washer either by gravity (the water flows down through the drain line and hose to the ground or to a drain in the floor) or by a water pump. The pump operates continuously as long as the motor is turned on, and the operator opens a valve in the pump to start the draining. The tub is then refilled with clear water for a deep rinse, with agitation.

In a *wringer* washer, the mangle is turned on by a lever. This engages a vertical shaft that transfers power from the drive motor to the mangle gear train and rollers. The rollers are made of soft rubber or composition and are adjusted with a pressure-regulating knob. A safety feature on most machines springs the entire mangle assembly open if a bulky object gets between the rollers.

In *twin-tub* conventional washers, the user places the damp clothes in a spin basket which is made to rotate at high speed by engaging another clutch lever. Most twin-tub washers, however, have a basket of small diameter, that requires a much higher rate of spin than the larger diameter basket of automatic washers. Some older twin-tub models have no safety switch to stop the spin basket when the access door is opened. All later models do have some such device, as well as a braking mechanism to bring the spinning basket to a stop as quickly as possible.

Components and Assemblies

To service a washing machine, the repairer must understand the functioning of each component and the machine as a whole. Since there are so many makes and models of washers, it is not possible to describe every one. However, most washers operate on the same general principles and use the same general types of components.

Washers are composed of three major assemblies: (1) the mechanical system, (2) the water system, and (3) the electrical system.

The **mechanical system** includes the main-drive motor, the gear train, and the basket-drive and brake assembly.

The *gear train* in agitator washers may be either of the sector gear, connector rod, or the rack-and-pinion gear type.

In the rack-and-pinion type, a pinion gear is driven by the main belt, taking power from the motor by means of a system of pulleys. The pinion gear drives a larger diameter, main gear pulley. By varying the sizes of the pinion gear pulley, the pinion gear, and the main-drive gear, a speed reduction is effected so that the main-drive gear revolves at about 120 rpm. The main-drive gear is usually mounted on an eccentric stud to permit adjustment of the gear mesh for quiet operation.

A stud mounted on the main-drive provides a bearing surface for a connecting rod, which is machined at its other end with a row of gear teeth, called a rack. As the main-drive gear rotates, the connecting rod is moved back and forth at about 60 complete strokes a minute. The rack end of the connecting rod meshes with the teeth on the agitator gear. This imparts an oscillating motion to the agitator, which travels about 180°, first in one direction and then the other, also at about 60 complete movements a minute.

In a variation of this method, a sector gear is used in place of the rack gear. A pinion gear drives a larger main-drive gear, as in the previous example. A connecting rod is attached, through bearing surfaces on both ends, to the main-drive gear and a sector gear, the latter pivoting on a stud through a 180° arc. The sector gear meshes with the agitator gear to provide oscillation.

In both methods, the drive belt is operating continuously as long as the motor is turned on. This means that the agitator would oscillate continuously if some method were not introduced to disengage the gear train at the appropriate points in the washing cycle. This is accomplished by translating the electrical impulse furnished to a solenoid plunger into mechanical action.

However, the amount of force exerted by a solenoid plunger would never, by itself, be enough to disengage the gear train of a mechanical system powered by a ⅓ or ½ hp motor. Some other means of actually extracting a gear from the train must be used. Thus, the extraction is initiated but not actually accomplished by the solenoid plunger. Here is how one such system works. The location chosen for the breaking of the gear train is the meeting of the rack or sector gear with the agitator shaft. This provides the greatest amount of cushioning for the sudden shock of the meshing of the gear tooth.

The agitator gear may be moved to one of two positions on the agitator shaft. In its upper position, it locks with the shaft by means of a pin. A spring exerts pressure downward, keeping the gear from locking with the agitator shaft. In its lower position, the agitator gear oscillates freely, entirely independent of the agitator.

In both agitator and tumbler washers, the cylinder basket is driven by a V-belt riding on a drive pulley. In agitator washers, the same belt drives both the basket and the pinion gear pulleys.

In tumbler washers, the speed of the cylinder basket must be reduced from about 600 rpm in the spin cycle to 50 or 60 rpm in the wash cycle. This is done by a transmission or speed-change unit actuated by a solenoid plunger, much the same way as in the agitator gear train.

A cylinder basket loaded with wet clothes and spinning at 600 rpm develops many hundreds of pounds of inertia force. Not only is this force dangerous, but it tends to keep the cylinder basket spinning for a very long time after the driving force is removed. Some sort of braking system is therefore required, for both safety and efficiency.

The mangle of a conventional washer is an assembly designed to wring out moisture from wet clothes as they pass between two rubber or composition rollers under controlled pressure. Power for the wiring is taken from the drive motor through a wringer drive shaft turning a system of gears at the lower roller. The upper roller idles in most machines. A lever engages the gear train to operate the rollers, usually in one of three positions—forward, reverse, and stop.

A safety device to relieve the pressure on the rollers is usually provided. In some models, this device is automatic, springing open the entire mechanism when a bulky, unyielding object attempts to go through the rollers. In others, a large button or bar on the top of the assembly must be struck to relieve the pressure. In either case, resetting the rollers is simply a matter of depressing the upper roller housing until it locks.

Mangle assemblies are designed to pivot on the wringer drive shaft housing so that the entire assembly may be swung out of the way during the wash cycle, if desired.

Agitators in today's washers are made of molded plastic, while earlier ones were made of cast aluminum. Some have relatively straight vanes with a slight sweep, similar to a triangular sail before a breeze. Others have undulating shapes that cause the clothes to rise and fall as well as oscillate horizontally. Extra precautions are taken by manufacturers to ensure a positive lock between the agitator and its shaft. In some, a press-fitted locking lug that fits into a hexagonal tapered hole in the agitator body provides a firm seating for the agitator to prevent whipping. If this lug has to be removed, for access to the gear case and other mechanical components, a special lug-puller tool must be used.

Not all washers have the type of agitator that oscillates through an arc. One popular make causes the agitator to move up and down in a fast pumping motion, instead of turning. Still another moves the agitator in a slow, off-center movement that does not turn on itself.

Cylinder baskets in most washers are made of porcelain-enameled steel. Holes in the sides and bottom permit the free passage of water in and out, even when loaded with clothes. The basket of an agitator washer, being positioned upright, usually has a conical bottom so that no dirt or residue is trapped and to ensure complete drainage.

A tumbler washer basket usually is fitted with baffles placed at right angles to the circumference to help carry the clothes to the top as the basket revolves. The clothes then drop of their own weight into the water. Baffles also help create more turbulence to loosen dirt more efficiently.

Both tumbler and agitator washers require an outer tub to hold the water through which the cylinder basket revolves. Outer tubs are also usually made of porcelain-enameled steel and have holes fitted with seals and sleeves for the various hose connections. A large drain hole in the bottom of the tub may have a baffle to prevent the air lock that sometime occurs when swirling water tries to go down a drain. Other baffles may be located at strategic places on the tub bottom to increase turbulence.

The **water system** in an automatic washer consists of a series of valves, a water pump, and various accessories such as dispensers, filters, and hoses. Water enters the tub through an inlet valve, which may or may not have an automatic temperature control for mixing hot and cold water. Usually, water enters the machine from its own pressure. As the water level rises, it actuates the fill switch, closing the circuit to the agitator control solenoid, and the machine begins the wash cycle.

In some machines, the water pump also recirculates the water, taking it from the bottom of the tub and forcing it through an inlet above the water level near the top of the tub. This recirculation ensures that the soap and bleach are thoroughly mixed with the wash water. Energizing a solenoid on the water pump permits the passage of the recirculated water driven by the recirculating impeller.

Water is ejected from the tub by the discharge impeller of the water pump. Discharge is effected by flapper valves in the body of the pump, which are actuated by the same mechanism that motivates the gear extraction in the drive system.

Three types of basic solenoid coils and plungers are used in washers today. With a *single solenoid shut-off valve*, the solenoid performs only the function of shut-off. The mixing of the incoming hot and cold water for desired wash and rinse temperature is done at the faucets by the user. A *double solenoid shut-off valve* allows three water temperature selections—hot, warm, and cold. Energizing the cold water solenoid allows only the passage of cold water. Energizing the hot water solenoid allows only hot water to enter. When both solenoids are energized, both hot and cold water enter, for a warm wash. A *triple solenoid shut-off valve* allows four water temperatures—hot, medium, warm, and cold. It has a mixing chamber in which cold and hot water in varying amounts are combined for the desired wash temperature.

The actual temperature of the wash water depends on the temperature of the water in the hot water heater and the temperature of the cold tap water. In a double-solenoid inlet valve, the temperature of the warm wash is equal to half of the sum of these two temperatures. For example, if the hot water heater temperature is 160°F and the cold tap water is 50°F, the temperature of a warm wash would be 105°F.

The **electrical system** used in washers is 110 volts, 60 hertz. Electricity is used to power not only the drive motor and the timer motor, but also the various electrical components that control the flow of water in and out of the machine. Wiring diagrams for particular models are provided in the service literature from the manufacturer.

The *timer* is the heart of the control for all functions of an automatic washer. It consists of a synchronous motor, of the type found in clocks, which drives a pinion gear meshed with a drive gear in the timer assembly. This assembly may consist of a series of cam wheels or disks with inclined projections on their edges. As the cam wheels slowly revolve, cam surfaces rise to make contact with switch levers. These, in turn, open or close electrical circuits to solenoids in the mechanical system.

Some washers and dryers are advertised as "solid-state" appliances. This refers to the use of *thermistors* for sensing heat in specific portions of the cycle. In the washer, the thermistor is used to sense and regulate the heat of the incoming water. In the dryer, a series of thermistors is used to register the temperature of air at the duct outlet, replacing bimetal disk thermostats. Because of their infinite setting potentials, thermistors are more efficient in regulating temperatures than the off-on thermostatically controlled switch.

The *lid switch* is connected between the spin solenoid and the timer. This switch stops the spinning when the door is opened. This is a safety measure added to prevent accidents. In the past, people have tried to add a garment to the spinning clothes and been seriously injured when the powerful force generated by the heavy basket dragged both the garment and an arm into the machine.

Mercury switches are popular for use as lid switches since they are relatively simple and foolproof. A bubble of mercury normally rests in contact between two switch terminals when the lid is closed. As soon as the lid is opened even slightly, the bubble of mercury rolls away from the contacts, and the circuit is instantly opened. This not only interrupts power to the basket-drive assembly, but also applies the stop brake.

The most popular type of motor used on washers is a ⅓ to ½ hp, 110-

volt, 60-hertz, capacitor-start motor. It has a thermal overload protector that disconnects the motor from the circuit if an overload occurs. The protector resets itself when the motor has cooled enough, and operation can resume. However, if the condition that caused the overload is not corrected, the overload protector will soon open the motor circuit again.

In washers with a selection of two speeds, the drive motor has two run windings. The wiring harness is connected to three terminals at the motor. This permits selections such as *normal action* or *gentle action* to bring one or the other run winding into operation to achieve different speeds.

Service literature published by the manufacturers usually includes wattage ratings of the motor under both load and no-load conditions, which will be helpful in diagnosing some of the causes of failure.

Exercise

1. What are the two main types of washers?
2. What happens when the operator makes a fill selection?
3. How are agitators driven?
4. What types of gear trains are used in agitator washers?
5. What happens after the agitation or wash cycle?
6. Describe the three major assemblies of washers.
7. How is the cylinder basket driven in both agitator and tumbler washers?
8. Describe the safety device on mangles.
9. How is water ejected from a tub?
10. Name the three types of solenoid coils and plungers.
11. What is the function of the lid switch?

K-3

Electric Dishwashers

Objectives: After completing this assignment, you will be able to—

1. name the two general types of dishwashers;
2. discuss the operation of the impeller dishwasher;
3. explain the difference between the spray-arm dishwasher and the impeller dishwasher;
4. discuss the operation of the spray-arm dishwasher;
5. tell how dishwashers are electrically powered; and
6. describe the pump used on dishwashers.

The principle of operation of a dishwasher is simple and direct. Hot water and detergent, driven at high speed, are sprayed over dirty dishes by a motor-driven impeller or by a rotating spray arm from which the water emerges. After several rinses and drains, the same impeller wafts air warmed by a heating element over the dishes to dry them.

Dishwashers are of several kinds, mostly related to their mounting and location in the kitchen. The *portable* dishwasher may be wheeled over to the table, for loading the dishes. The dishwasher is then wheeled back to its normal location at or near the sink, where water connections are made, the line cord plugged into an outlet, and the machine turned on.

The *undercounter* model is designed to fit just under the standard-height countertop next to the sink. Water and electrical connections are permanent. In most models, the dishwasher is directly wired to the distribution box. Some undercounter models have a bottom-hinged door, which opens like a range oven door. Trays slid out to hold the dishes, or the entire tub rolls out for top loading.

Dishwashers are also available as *combination sinks* that include a garbage disposer.

With respect to functioning, there are two general types in popular use. In the *impeller dishwasher,* a motor-driven impeller blade splatters water in all directions inside the tub. In the *spray-arm dishwasher,* water is recirculated by a separate pump and emerges from the nozzles of the spray arm, which rotates by recoil, much like a lawn sprinkler. In both types, the dishes are washed by a combination of the mechanical force of the water striking and dislodging soil, and the dissolving action of the hot, sudsy water on grease and other foreign matter.

Operation of Impeller Dishwasher

In the typical impeller dishwasher, the dishes are arranged in the tub so that they will drain properly and not trap water. The tub is closed, and the interlocking door switch turned on. The tub cannot be opened in any dishwasher unless this switch is turned off, to prevent water from spilling into the room. The timer switch is then advanced to *start,* and the machine turns on.

A timer motor, similar to the one in automatic washers, advances a series of cams, whose raised surfaces open and close circuits in sequence in the course of their slow rotation. The first cam closes a circuit to a solenoid-operated, water inlet valve. Water for the dishwasher is connected to the hot water pipe only. There is no mixing or selection of hot, warm, or cold water, as in a clothes washer. Recommended water temperature, received directly from the hot water heater, is 140°F to 160°F. Any water temperature lower than 140°F will result in dishes that are not only filmy and spotted but also less germfree than they would be at the proper temperature.

The inlet valve operates as a timed fill, with the amount of flow governed by a flow washer. A typical fill cycle lasts about 60 seconds and admits about 12 pints of water, flowing at a rate of about 1½ gallons per minute. Some dishwashers have a pressure switch, similar to the one in automatic washers. However, the function of the pressure switch in a dishwasher is to shut off the water in case the proper water level is reached before the timer motor shuts off the water inlet valve. This may happen because of the variations in water flow rates. Thus, the pressure switch in a dishwasher is a water-level safety device.

When the user advances the timer switch, water enters the tub through the water inlet valve. At the same time, the main motor circuit closes, and the impeller begins to rotate at a motor speed of about 1,700 rpm. As water reaches the impeller, it is driven forcefully against the dirty dishes, to scrub-rinse them and soften the soil in preparation for washing.

The timer cams having advanced after a short period, the circuit to the solenoid valve is opened, and the water flow into the tub is stopped. The impeller continues to rotate for a short time, until the timer cams advance and the circuit to the main motor is opened. After a brief pause, the motor circuit is closed again, but this time in reverse.

Most dishwashers use a shaded-pole, variable-speed, reversible motor for this purpose. The reverse rotation of the motor causes the drain pump to function. A system of valves and the arrangement of the interior-pump impeller blades cause the pump to idle in one direction, and pump water in the other direction. Water is pumped directly into the sink drain.

The drain cycle is also a timed cycle, allowing ample time for the dishwasher tub to be drained. During this cycle, the main motor impeller is mechanically disconnected and does not move.

After the first rinse cycle, some dishwashers provide a second rinse. Now follows a washing period of about 5 to 7 minutes. Water is admitted to the tub for the wash cycle in the same manner as for a rinse. After a short period during which the impeller drives water against the dishes, a cam on the shaft of the timer motor dislodges a detent lever, and the detergent cup is upended by the force of a spring, spilling dry detergent into the tub. The detergent causes low sudsing, and the hot, sudsy solution washes away the presoftened dirt and emulsifies greasy films and stains.

When the washing period is over, the timer cam advances, and draining takes place. This is followed by at least two rinses, each followed by a drain period. After the final rinse, the main motor impeller is driven at high speed, becoming a fan capable of delivering a relatively large volume of air. At the same time, a circuit to the heating element located in the bottom of the tub is energized.

Heating elements are rated from 600 to 1,000 watts and are used to assist in the drying process. Air warmed by the heating element is circulated throughout the tub by the main motor impeller. Venting is accomplished by water-baffling holes in the tub gasket, which lead steam out of the interior of the tub. The drain pump would also assist in this function in those dishwashers in which it operates during the warming and drying period. After a drying period of about 25 minutes, the timer advances, and all circuits are opened.

Operation of Spray-Arm Dishwasher

The spray-arm circulating dishwasher operates a little differently from the impeller type. The main differences are that the spray-arm type has (1) a separate motor for each of two pumps, a recirculating pump and a drain pump, and (2) a spray arm in place of the main motor impeller.

In the spray-arm dishwasher, water is admitted in the same manner as in the impeller type, through a solenoid-operated, water inlet valve. Water runs down into a sump, passing through a filter screen. From the sump, it is forced under pressure into the spray arm by the recirculating pump. The nozzles on the spray arm are slanted at an angle so that the recoil action of the water ejected from the nozzles drives the spray-arm shaft to rotate at high speed. Thus water is sprayed into every angle and crevice formed by the dishes on the racks.

The spray-arm dishwasher filters small particles out of the wash water before they can reach the recirculating pump and clog the relatively small nozzle openings of the spray-arm shaft. The circulating action of the water causes particles to gravitate toward the center of the slope formed by the tub. Both coarse and fine particles roll down the slope and onto a fine screen, with a cone-shaped hole in its center. A coarse-screen basket in the hole traps and holds those particles too large to go into the drain pump. Smaller particles pass through the basket and are held temporarily inside the cone-shaped part of the fine-mesh filter screen, where they are prevented from entering the inlet to the recirculating pump. Filtered water now passes through the fine-mesh screen, where it is admitted to the recirculating pump and on to the spray arm.

When draining occurs, all the smaller particles held temporarily in the cone-shaped filter pass down into the drain pump and out the drain. The larger particles trapped by the coarse-screen basket are lifted out with the basket, which should be emptied after each use or as necessary.

Electrical Assemblies

Dishwashers are powered by a 110-volt, three-wire, single-phase, alternating current, rated at from 12 to 15 amperes. Because of the relatively high power consumption of a dishwasher at full load, it should be wired to its own branch circuit, except for portable dishwashers.

The timer uses a synchronous motor that drives a mechanical train, which in turn drives a cam wheel, or a series of cam wheels. The cam advances in increments of time, usually about 45 seconds in duration. Normally, the timer motor operates continuously throughout the cycle of operation. In some models, the timer has a master line switch wired in series. Its purpose is to interrupt the circuit whenever the timer dial is being reset, particularly in those machines which offer a selection of short and long cycles of operation.

Dishwasher heaters are of the tubular construction. In some dishwashers they serve the dual purpose of supplying auxiliary heat for the wash and rinse water and as a heat source in the drying cycle. They may be anywhere from 600 to 1,000 watts. The wire coil is completely enclosed in a magnesium alloy tube and held from contact with the tubing by procelain or other nonconducting spacers. Rubber or neoprene washers make a waterproof seal at the two points where the heater element enters the tub.

Mechanical Assemblies

The few purely mechanical parts of a dishwasher, unlike an automatic clothes washer, make an appliance that is remarkably servicefree, considering all the functions it performs.

Dishwashers, whether of the impeller type or the spray-arm type, use a pump mounted directly on the drive motor shaft, with no gear train or drive belts. Inside the pump, a series of flapper valves control whether the pump should drain or idle.

In the reversible motor dishwasher, when the motor is turning in a clockwise direction (looking toward the motor), washing is taking place at a rate of 3 gallons or more per minute. In the counterclockwise direction, pumping occurs. In some models, the main motor impeller stops during drain. In others, the impeller turns but, because of the shape of the vanes, has little or no effect on the water in the tub.

The detergent cup mechanism may take many forms in different makes, but the principle is similar in each. At a given point in the cycle, a trigger mechanism is tripped and the cup is overturned, spilling the detergent into the wash water. The turning of the timer shaft, making one complete revolution during the entire cycle, turns a cam with it.

When detergent is loaded into the machine, the cup is turned upright manually, against the force of a spring. A plunger engages with the cup, preventing it from overturning. The other end of this plunger is pressed against the face of the cam wheel on the timer shaft. When the cam wheel rotates to a point where the cam surface makes a sudden drop, the plunger is forced by its own spring down into the lower surface of the cam wheel. At the other end, the plunger disengages from the cup, which snaps into the overturned position, spilling the contents.

A lid on detergent cups keeps the detergent dry until it is ready to be added to the water. If the detergent becomes damp in the cup, it may pack down and fail to dispense. Some means of opening the lid is also usually provided so that wash water can get into the cup after it has overturned to wash it clean.

Other detergent cup mechanisms may use electromagnets to initiate triggering, although most of these would still depend on the force of springs to accomplish the actual overturning of the cup. Some dishwashers have two dispensing cups, one for the regular wash and the other for a rinse conditioner.

Exercise

1. What are the two general types of dishwashers?
2. How does the timer motor work?
3. What is the length and flow rate of a typical fill cycle?
4. What is the function of the pressure switch in a dishwasher?
5. What kind of motor do most impeller dishwashers use?
6. What happens to the main motor impeller during the drain cycle?
7. What are the main differences between the impeller dishwasher and the spray-arm dishwasher?
8. What makes the spray-arm shaft rotate at high speed?
9. What devices are used to filter out particles from the wash water in spray-arm dishwashers?
10. How are dishwashers electrically powered?
11. What is the dual purpose of the heater in some dishwashers?
12. Describe the pump used on dishwashers.

K-4

Electric Disposers

Objectives: After completing this assignment, you will be able to—

1. discuss the basic operation of electric disposers;
2. discuss the two types of disposers;
3. give the characteristics of a disposer motor; and
4. discuss the construction features of a disposer.

Basic Operation

The disposer is a grinding device driven by an electric motor and housed in a sealed metal unit. The housing is sometimes insulated to deaden the sound. The disposer is installed directly beneath the sink, which must have a 3- to 4-inch drain opening. A sufficient supply of cold water must be available for entering the top of the disposer to flush away all ground wastes.

The disposer does not chop or cut because it has no blades. It *grinds* and *wears away* at the garbage until it has been ground into small bits. When the switch is turned on, the electric motor turns a round table at speeds up to 8,000 rpm. The garbage on the table is forced against the sides of the chamber where the grater or grinding ring is located. The force of the food waste, as it is spun at high speed, is great enough to make it drop through the tiny openings that lead into the drain line. Small projections, called *lugs*, are built in the spinning table to keep the food waste moving along and to force it against the grinding ring.

Types of Disposers

Electric garbage disposers are manufactured in two types, continuous-feed and batch-feed. Both operate in a similar manner, and both do the same job in about the same amount of time.

Continuous-feed disposers are more popular because they operate continuously. Wastes and garbage are fed into the chamber after the cold water and the switch are turned on. The cold water should run at a moderate flow while the disposer is operating and for a few seconds after it has been turned off. This flushes the system of all bits of waste and moves it to the sewer or septic tank.

A rubber baffle inserted in the opening prevents water and waste from being thrown into the sink from the grinding chamber. More waste can be forced through this flexible baffle into the disposer as long as the water and switch are left on.

To use a **batch-feed** disposer, first place the food wastes into the grinding chamber, and then lock a cover into place. Turn on the water, and turn a locking lid. This activates the switch for the motor. After the contents of the chamber have been ground, the locking lid may be removed and more waste added. The motor always turns off automatically when the lid is turned to the unlock position.

The greatest advantage of the batch-feed disposer is *safety*. A person with a small hand can accidentally push the hand inside the grinding chamber of a continuous-feed disposer. A child should never operate this machine. Take care to never force your hand at any depth into the opening. Be sure that no silverware, fruit pits, or bones are mixed in with the food wastes. Bits of metal or other hard objects could be thrown out and cause injury. The disposer may also be damaged from this type of abuse. Always check the grinding chamber before turning it on to see that foreign objects have not accidentally fallen in.

Power Source

Large disposers have ½-hp electric motors, while smaller models usually have ⅓-hp motors. Inexpensive disposers have single-speed motors and are protected by built-in circuit breakers or overload protectors that can be reset manually if a jam occurs.

More expensive models have multispeed, capacitor-type motors. They have a lower rpm factor, but are stronger and have a longer life. The capacitor allows the motor to gain its maximum speed without strain or overload. Better electrical motors have shielded motor windings to prevent damage from corrosion or moisture. They also have self-lubricating bearings, overload protector switches with reset buttons, and polished steel drive shafts. Some better motors have a reverse switch to assist in relieving a jam.

Construction Features

A home that has a disposer probably has a dishwasher also. The dishwasher usually has a flexible drain hose that connects directly to the upper endbell of the disposer. When the dishwasher pump empties into the disposer, any food particles that may have come through are lodged in the grinding chamber until the disposer is turned on. Most people find that when the dishwasher has a direct connection to the disposer, the disposer must be turned on and emptied completely before the dishwasher is operated. If this is not done, collected food wastes will slow the flow of water from the dishwasher. This may create an overflow from the back pressure on the dishwasher pump.

Most disposers are extremely noisy if hard wastes are being ground. These sounds are muffled in several ways. At the top end is a rubber gasket that mounts between the sink opening and the outer rim. This gasket absorbs the vibration from the motor and the grinding mechanism. The upper end of the neck that feeds into the grinding chamber is another area where noise is created in the hopper or shredding mechanism. The neckpiece is usually made of high-impact plastic or other noncorrosive synthetic material. If the upper chamber is made of stainless steel, it is usually wrapped with a soundproofing material. The upper neck is found only on batch-feed models, and the soundproofing is found only on more expensive models.

Noise can be dampened on continuous-feed models by partly replacing the lid. Do not restrict the flow of water going into the grinding chamber.

Grinding Mechanism

The grinding mechanism has three main parts. The *grinding table* has small holes for the ground waste and water to pass into the drain. Spaced on the table are metal *lugs or impellers,* which force the food waste against the *shredding ring*.

Most good-quality disposers have jam-free impellers. These swing slightly to allow extremely hard objects to pass by without catching on the shredding ring and stopping the mechanism. On some models, an automatic device backs the impeller away from the object to allow the motor to restart if a jam has caused the overload to cut the power. On other models, the jammed grinding table must be backed off manually, and the reset button on the motor pushed to reactivate the power source.

Endbells

The upper endbell forms the grinding chamber or hopper. The lower endbell forms the drain chamber below the grinding table. These chambers must be constructed of stainless steel for the best performance. Both the endbells and grinding mechanisms are subjected to much corrosion and abuse. Some less expensive endbells are coated with plastic to prevent corrosion.

Exterior Housing

The disposer assembly is encased in a metal housing. Chrome steel or plastic may be placed over the housing for appearance. Disposers housed in an exterior jacket usually have soundproofing material between the outer case and the inner housing. This insulating material is usually made of fiberglass or polyurethane.

A stainless steel elbow connects the drain chamber to the sink drainpipe above the gooseneck. To ensure perfect alignment and free-flowing drain action, the disposer should only be connected or disconnected by an appliance repairer. An inexperienced person may cause misalignment, which would impede the drain action, or joint leaks.

Exercise

1. What type of action takes place in a disposer?
2. In the spinning table, what keeps the food waste moving along and forces it against the grinding ring?
3. What are the two types of garbage disposers?
4. When are wastes fed into the chamber of the continuous-feed disposer?
5. What keeps water and waste from being thrown into the sink from the grinding chamber?
6. When are food wastes placed in a batch-feed disposer?
7. What is the greatest advantage of the batch-feed disposer?
8. What should always be checked before turning on a disposer?
9. What disposers have motors of the capacitor type?
10. What should be done if a dishwasher has a direct connection to the disposer?
11. What absorbs the vibration from the motor and the grinding mechanism?
12. How can noise be dampened on continuous-feed disposers?
13. Name the three main parts of the grinding mechanism.
14. What does the lower endbell form?
15. What insulating material is usually placed between the outer case and the inner housing?

Section

L

Gas Appliances

L-1. Natural Gas Use and Safety
L-2. Gas Ranges
L-3. Gas Dryers
L-4. Gas Water Heaters

L-1

Natural Gas Use and Safety

Objectives: After completing this assignment, you will be able to—

1. discuss how natural gas is obtained and transported;
2. identify the various types of gases; and
3. discuss the precautions to observe around gas.

Sources and Uses

Natural gas is restricted to the inflammable gases issuing from oil and gas reservoirs in the earth's subsurface. Samples of natural gas differ considerably, but its principal component is methane, or marsh gas (CH_4). The different percentages range from 81 for the natural gas recovered in Pennsylvania and West Virginia to 98 percent in some of the gas recovered in Oklahoma and Texas. Natural gas is the product of mineral and vegetable matter slowly decaying at a low temperature.

Natural gas is recovered from wells drilled at various depths, ranging from 250 feet to over 15,000 feet. The output from these wells varies from 500 cubic feet to 110 million cubic feet per day. The pressure of the gas varies from 1 psi to 3,000 psi in extreme cases. A pressure of 300 to 400 psi and a volume of 1 million cubic feet a day is considered a profitable commercial well.

Many of the original natural gas fields have been practically exhausted, and a large number of the producing companies have had to seek new fields. This has led to new discoveries, and new wells being drilled each day. The newest producing commercial field is on the Alaska North Slope, but there have been problems with the extreme cold and the distance the gas must be transported.

Natural gas is transported by pipelines that are interconnected with pipelines of many companies and nations. The North Slope wells are connected to the Canadian National Gas pipeline and then to the pipelines of various companies in the United States.

Natural gas has many uses in the home for cooking, house heating, water heating, and refrigeration. Home use of natural gas has increased about 2 percent a year since 1942. Commercial use has increased about 8 percent a year since then. No other countries use as much natural gas as the United States and Canada. Natural gas is used very little in Europe and the Far and Near East. Mideast countries use natural gas to a larger extent since most of the oil and gas there was developed and controlled by U.S. and Canadian oil and gas companies.

Types of Gas

Three main types of gases are used as fuel gases in appliances—manufactured, natural, and liquefied petroleum (LP). A fourth type, known as "mixed" gas, is merely a mixture of manufactured and natural gases.

Manufactured gas is obtained as a by-product in the processing of coal. There are two primary types, coke oven gas and carbureted water gas. *Coke oven gas* is produced by cooking coal with external heat while at the same time denying it contact with air or oxygen. *Carbureted water gas* is produced by introducing live steam on a burning coal or coke bed. This forms a compound composed principally of hydrogen and carbon monoxide, which is then enriched with oil-producing gas. Manufactured gases are lowest in heat-producing qualities, which range from above 500 to 600 Btu per cubic foot.

Two **liquefied petroleum** gases are produced as a by-product of petroleum refining. One of these, *butane*, has a very high heat value of about 2,500 Btu per cubic foot. The special properties of LP gases permit them to be stored and delivered in a liquid state under a moderate amount of pressure. These gases are sometimes called "bottled gas." LP gas is used mainly in rural areas that are not served by utility pipelines.

Orifices

Differences in these types of gases require that gas appliances be altered with respect to the size of the orifice on burners. An orifice is the outlet for the gas on the appliance. Distributors' stocks of appliances are equipped with orifices of the proper size for the type of gas being delivered in their area. In addition, a tag or some other means is used to identify the type of gas for which the appliance is equipped.

In some cases, utility companies switch from manufactured gas to natural gas, or vice versa. It is then the responsibility of the utility company to make any necessary alterations.

Adjusting the Flame

All gas burners are equipped with an air shutter that admits air in varying amounts to be mixed with the gas during the burning operation. To adjust the flame for maximum heat output, open the air supply until a soft blue flame is achieved. Gradually cut down the air supply until a yellow tip appears on the flame top. Now increase the air supply until the yellow tip barely disappears. The flame should be well defined with a blue inner cone.

Once the air shutter is properly adjusted, it should be locked in place with a setscrew. Apart from an occasional need for gas flame adjustment, gas burners require little maintenance except for cleaning the burner orifices.

Gas Safety

The gas used in the home is not normally dangerous to the health. Tests made with canary birds, who are very sensitive to poisonous gases, showed that they could breathe as much as 34 percent without negative results. The greatest danger is when a stove has been operated in a room without being connected to a flue. The air in the room can soon become depleted of oxygen.

Natural gas in its pure form is odorless. Thus, a chemical called Kap-Tan is added to give it a very strong odor that can be easily detected. This chemical is added to the gas at the first pump station after it leaves the wellhead.

There are some simple precautions to take if you smell gas odors. First, check all pilot lights in the kitchen and around the house. If the odor is faint, first check for a partly open burner valve. If the odor is overpowering, open a window, turn off any open flames, and leave the house or area immediately. Do not flip any electrical switches or use the telephone as it might cause a spark. Never strike a match or use a cigarette lighter. Use a neighbor's telephone or a public telephone, and call the local gas company. It is common practice for the gas company to send someone, day or night, to locate the problem. Never use any appliances if you smell the odor of natural gas. An accumulation of natural gas has the potential for a large explosion.

Exercise

1. Where is natural gas found?
2. How is natural gas transported?
3. How much has the use of natural gas increased each year since 1942?
4. Name the three main types of gases used in heating appliances.
5. What is mixed with gas during the burning process?
6. What LP gas has a heat value of about 2,500 Btu per cubic foot?
7. What new problems exist at the Alaska North Slope gas wells?
8. Who should you telephone if you suspect a gas leak?
9. What chemical is added to give an odor to natural gas?
10. What part of a gas burner should be cleaned periodically?
11. Name the two primary types of manufactured gas.
12. What health danger exists when a stove in use is not connected to a flue?
13. When is Kap-Tan added to the natural gas?

Objectives: After completing this assignment, you will be able to—

1. discuss the various controls on the gas range;
2. discuss the adjustment of the top burners;
3. name the types of lighters; and
4. discuss the oven temperature control system.

L-2

Gas Ranges

Modern automatic gas ranges include several features that have been perfected for ease and convenience in cooking. Top and oven burners have *automatic lighting* and *precision heat control*. *Impoved oven insulation* assures better heat distribution and prevents heat from entering the kitchen. New *low-temperature oven burners* assure the maintenance of a low oven temperature. New *round, horizontal flame top burners* with individual *heat sensors* make possible waterless cooking.

Parts and Controls

The top burners are located as close as possible to the range surface to be heated, but within the prescribed distance for proper flame control and proper gas combustion. The round and star-shaped burners are preferred for best performance because they conform more nearly to the shape of the vessels being heated.

These two burners have equally good design features in their air mixers. The round burner is the more popular of the two. It also provides a better supply of secondary air to all parts of the flame. However, the star-shaped burner is more effective because it gives a better distribution of gas.

The various controls on the gas range are the burner valves, lighters (both manual and automatic), oven heat-control thermostats, automatic pan control, and time controls (clocks, etc.). Figure 1 shows the location of the working parts of a typical gas range.

The valves control the gas supply to the burners. The two kinds are the *rotor* and the *plug-and-barrel*. These valves may be of the single- or double-duty type, depending on the particular gas volume control involved. Specifically, a double-duty gas valve is made so that it offers gas volume control of the center simmer, the main burner parts, and the combination of the simmer and main burner section.

A typical gas valve of the rotor type is shown in figure 2. These valves are right- and left-handed, depending on their location on the manifold assembly. Their direction of rotation is clockwise.

The principal parts of a single-duty top burner valve are a tapered plug, a barrel or body, a stop pin, a spring, a tail nut or cap, and an adjustable or fixed orifice hood.

The servicing of burner valves involves regreasing or tightening loose nuts so as to make the plug tight in the barrel. The designs and lubricants used today usually require no regreasing of valves. The grease used today will not break down, even under temperatures as high as 500°F. The most common valve problem is with the *orifices*, which occasionally become clogged. When they do, you must remove the valve and clean it. When the valve plug becomes so badly worn that the spring no longer holds the plug tight, the valve should be replaced. When replacing a valve, a new orifice must be supplied with the new valve.

Burner Adjustment

The adjustment of the *top burners* is very important for the proper heating and burning of the gas. When correctly adjusted, the total flame should extend a short distance above the burner grate. The flame spread for a correctly adjusted top burner is shown in figure 3. The flame spread should be determined with a cooking vessel placed on the burner.

The function of the *simmer burner* (fig. 4) is to maintain boiling temperature. Thus, as much attention must be paid to the simmer adjustment as to the regular, or giant, burner adjustment. If the simmer burner is adjusted properly, it will maintain up to 6 quarts of water at boiling temperature, provided the vessel is covered and enough heat is applied to the cooking vessel. The simmer flame adjustment should not be above the top of the burner grate. This adjustment is governed by the ignition of the flames on the simmer burner by the flame lighter.

Lighters

Lighters are divided into two major types, depending on the method used to ignite the gas. These are the top lighter ((push-button or swivel-joint-operated) and the automatic lighter. Older ranges use top lighters, and the more modern gas ranges use automatic lighters.

Top lighters should be adjusted so the top of the flame does not come in contact with any part of the lighter. The most common pilot outage is caused by the buildup of carbon and dirt in the dome and around the air ports of the hood. It can usually be corrected by drilling a ½-inch hole in the top of the hood. If the pilot goes out and the tip is clean, the push-

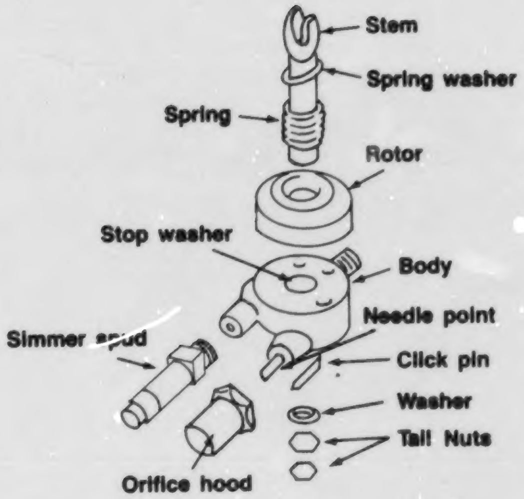

Stem
Spring washer
Spring
Rotor
Stop washer
Body
Needle point
Simmer spud
Click pin
Washer
Tail Nuts
Orifice hood

Fig. 2. Typical gas rotor valve

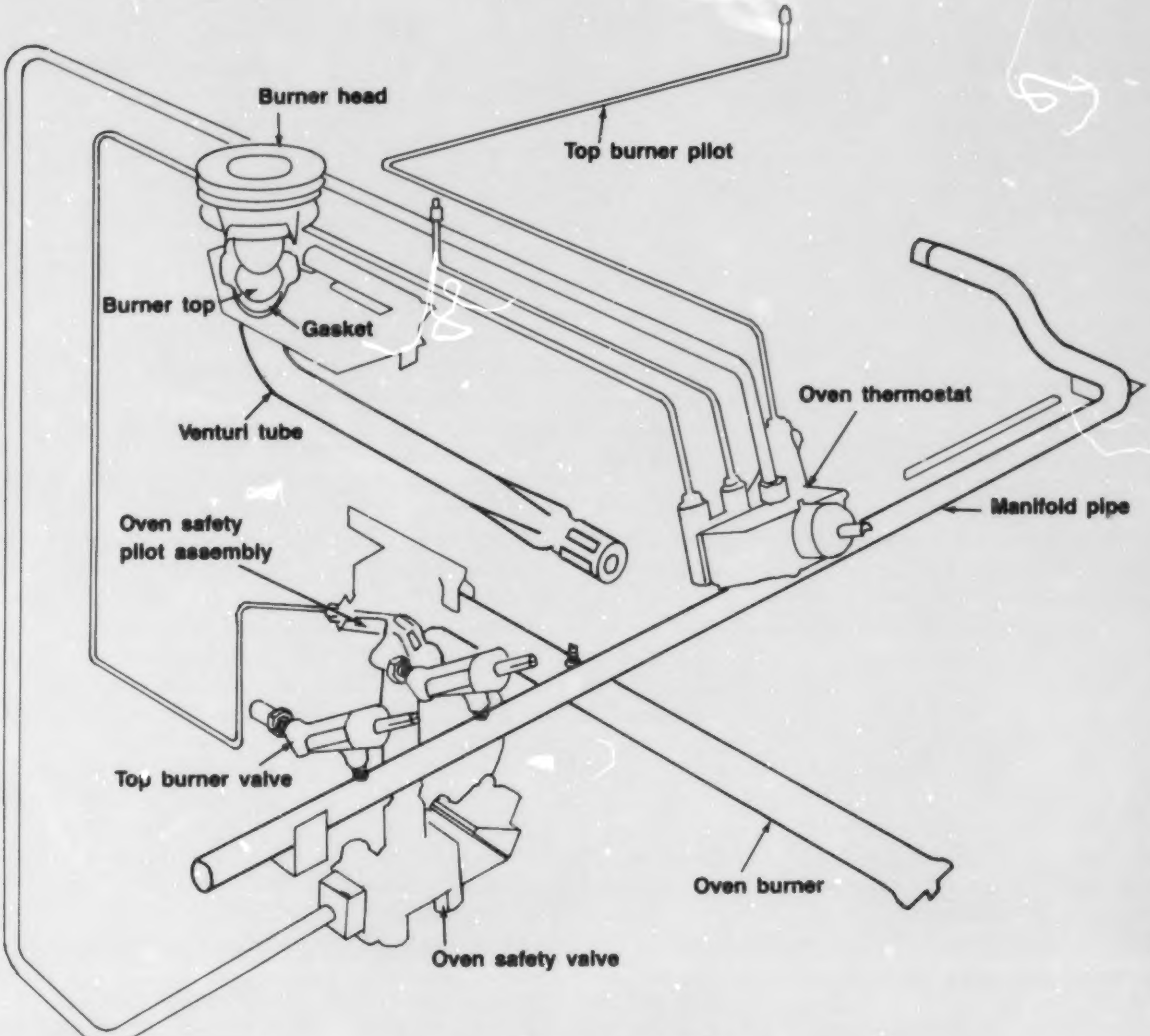
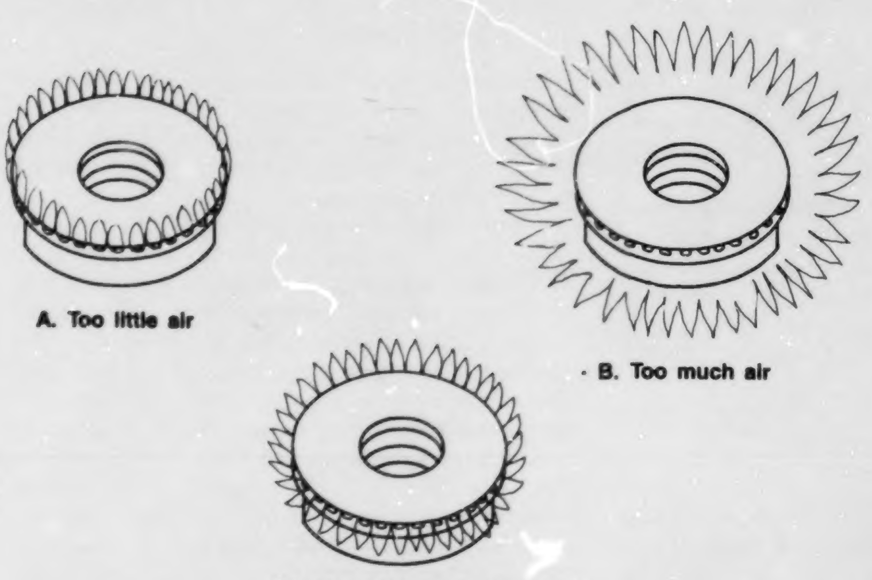

Burner head
Top burner pilot
Burner top
Gasket
Venturi tube
Oven thermostat
Manifold pipe
Oven safety pilot assembly
Top burner valve
Oven burner
Oven safety valve

Fig. 1. Location of components



C. Correct amount of air

Fig. 3. Burner adjustment

button assembly will have to be removed to clean the gas passages. Pilots are particularly sensitive to pressure variation or internal stoppage, which may be the cause of outage troubles. If a leak exists around the lighter valve stem, you must remove the nut and replace the graphite packing. The base of the lighter hood can be adjusted and located by means of the jam, or lock nut, so that the gas will burn properly through the center of the openings in the hood.

Automatic lighters are made with flash tubes that extend from the central protecting chamber, which contains the permanent pilot, to each of the burners. The speed and reliability of the flash ignition depend on top burner adjustment and correct positioning of all lighter parts.

When the burner gas valve is opened, gas flows through the burner orifice into the burner mixer throat, and in so doing injects a certain amount of primary air. This gas-air mixture arrives in the burner nead, and part of it flows out through a drilled port, usually called the lighter port. This lighter port is generally located at the end of one of the fingers of a star-type burner and below the level of the main burner ports. On round burners, it is located on the side of the burner head and below the main ports.

The lighter port is usually supplied with gas before the main burner ports. The stream of gas-air mixture leaves the flash tube and finally emerges at the far end of the tube next to the ignition pilot flame. If the burner gas and primary air supplies have been properly adjusted, the gas-air mixture will light from the pilot, and the flame will immediatley travel back through the flash tube, thereby igniting the gas mixture.

The main burner ports are then ignited, either by direct communica-

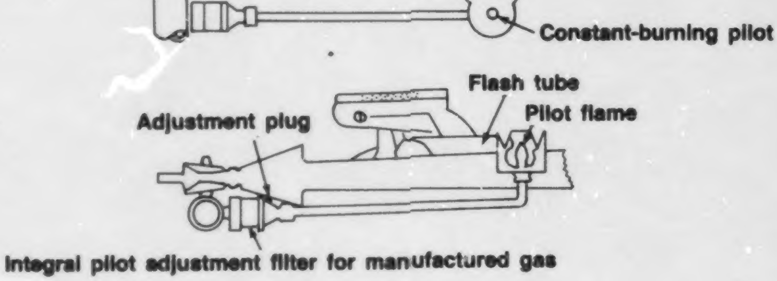


Fig. 4. Simmer burner control

[illegible] ith the lighter port or by the instantaneous flash created by the interruption of the backward travel of the flame. The gas at the lighter port remains lighted as long as the burner is operated. In general, the flame length should be such that the flame extends to the center of the tubes. These tubes converge in the permanent pilot. Delayed ignition or complete failure may be caused by pilot flames that are either too low or too high.

Oven Temperature Control System

Gas ranges use electrical components to control the gas flow, thereby achieving automatic control ovens and burners. A typical oven temperature control system uses three electrical components.

Thermostat. A standard range thermostat simply turns the current on and off. Manual operation of the thermostat, by the oven control knob, closes the contacts. Thermal action of the bulb, as the oven temperature is satisfied, opens the contacts.

Electric Gas Valve. This is a simple solenoid valve, actuated electrically. A gate opens and closes, allowing gas to flow to the oven burners or stopping the gas flow to the burners.

Flame Switch. This safety device ensures that no gas can flow to the oven burners unless the pilot flame is lit. Once lit by the service employee, it stays lit and does not interfere with the operation of the electric gas valve unless the pilot flame goes out. The flame switch is designed around a slim tube of mercury positioned so that the tube is heated by the pilot flame. When the flame is on, the mercury in the tube expands, closing electrical contacts in the electric gas valve circuit and permitting the gas valve to open. When the pilot flame goes out, the mercury contacts open the electrical circuit. Further manual operation of the thermostat will have no effect on the electric gas valve, which stays shut off until the pilot flame is lit once again.

Exercise

1. What are the advantages of the star-shaped burner?
2. What controls the gas supply to the burners?
3. Name the principal parts of a single-duty top burner valve.
4. What is the most common problem with burner valves?
5. What should be used when determining the flame spread?
6. What is the simmer flame adjustment governed by?
7. What are the two major types of lighters?
8. What are pilots particularly sensitive to?
9. What happens if the burner gas and primary air supplies on automatic lighters have been properly adjusted?
10. How does the electric gas valve operate?
11. What does the flame switch do?
12. What is the purpose of a thermostat?
13. What must be done if there is a leak around the lighter valve stem?

L-3

Gas Dryers

Objectives: After completing this assignment, you will be able to—

1. discuss how the controls of a gas dryer operate;
2. describe dryer motors;
3. discuss the different components of a gas dryer; and
4. explain the need for a vent on a gas dryer.

The controls and heater assembly of a gas dryer are far more complex than those in electric models because of the requirement of a pilot flame and the on-and-off cycling of the gas flow to the main burner.

Dryer Operation

To start the gas dryer, you must first light the pilot burner. This is done either by applying a flame to the pilot burner or, in some models, by means of an electric "spark plug" or platinum coil. In either case, the flame of the pilot burner heats a thermocouple, which generates a small electrical current. This current is strong enough to hold the plunger of a solenoid valve in the open position, permitting gas to flow to the pilot and to the main-burner solenoid valve as well. In flame-lit pilots, the flame remains burning as long as the main gas supply valve is turned on. Pulling the power cord from the wall outlet will not cause the pilot flame to go out, since the electrical current that holds the solenoid pilot valve open is self-generated in the thermocouple. In models with coil-lit pilots, however, the timer circuit interrupts the current to both the main motor and to a 24-volt circuit that supplies current to both the main-burner solenoid and the pilot solenoid. In this case, the pilot flame goes out when the drying cycle is completed.

By turning the timer mechanism, which may be either spring-loaded or motor-driven, contacts are closed, causing current to be applied to the main motor. It starts, actuating both the clothes drum and the blower motor. When the motor has reached about 1,400 rpm, a centrifugal switch on the motor housing closes the circuit to the main-burner solenoid. On the same circuit with the centrifugal switch is the high-limit thermostat, the cycling thermostat, and the auxiliary control thermostat. Since temperatures within the dryer at the start are below normal operating temperature, the main-burner solenoid is permitted to open by the various controlling thermostats (which are normally closed), and the main burner ignites.

Airflow set up by the blower system draws air into a flue below the main burner duct. Here it is heated and enters the revolving drum through holes in its face. The warmed air circulates through the clothes which are tumbling in the drum. Then it is drawn through the blower and out the exhaust duct, its temperature being sensed by the cycling thermostat. When the temperature of the exhaust air begins to climb as the clothes approach the final stages of drying, the cycling thermostat opens the circuit to the main-burner solenoid and closes a circuit to the auxiliary control thermostat. A cool-down period is followed by a heat-on period, until either the timer mechanism or the achievement of shut-off temperatures in the automatic system shuts off the dryer.

Dryer Components

Power Cord and Plugs. These are usually of the three-prong type, with the third prong being a cabinet ground. Most appliances are provided with an alternate ground wire and harness for attaching to the nearest suitable ground. Local electrical codes will indicate whether or not adapters for wall outlets may be used along with the alternate ground harness.

Motors. Dryer motors are usually ¼ to ⅓ hp, 115-volt, 60-hertz, split-phase types of about 1,725 rpm. Gas dryers, unlike electric ones, require only regular 115-volt house current for operation. A shaft protruding from both ends of the motor provides a power takeoff for the revolving drum on one end and the blower on the other.

Main-Burner Gas Solenoids. These may be actuated by either 115 or 24 volts, the latter being stepped down by a transformer. The gas solenoid is wired in series with the control thermostats and the centrifugal switch. The centrifugal switch is extra insurance against dangerous buildup of high heat, opening the main-burner valve only after the motor reaches run speed.

Timers. Timers may be driven by a spring-wound clock mechanism or by an electric motor.

Automatic Controls. These controls for heavy and light loads, and so forth, are normally of the potentiometer type, permitting selection of various degrees of resistance ahead of the auxiliary control thermostat. By reducing or increasing amperage, the wattage consumption of the bias heater of the auxiliary control thermostat is carefully controlled. This causes the auxiliary control thermostat to open later or sooner as a measure of controlling the length of the heat-on cycle.

Thermocouples. When the pilot burner is lighted, a hot and cold junction of iron and nickel creates a current, measured in millivolts of electricity, in a coil around the solenoid valve plunger. The current is strong enough to hold open the plunger, but not enough to overcome the force of a spring initially. Therefore, it is necessary to press a button to hold the plunger open against the force of the spring until the thermocouple joint warms up enough, about 20 to 30 seconds, after which the small thermocouple-generated current is sufficient to hold up the solenoid. Any momentary interruption of this small current will cause the solenoid plunger to close the valve, shutting off the supply of gas to both the pilot and the main burner. This valve will not reopen by itself. The start button must be pressed again, and a flame applied to the pilot burner.

Spark Plugs or Glow Coils. A 24-volt transformer supplies current to a 24/2.5-volt transformer that energizes a glow coil at the pilot burner. The current causes the coil of platinum wire to give off an intense heat, enough to ignite the gas coming out of the pilot burner. Once ignited, the gas flame is directed against a bimetal strip, which instantly snaps to the open position, interrupting the flow of current to the glow coil. The extremely low voltage is necessary because a higher potential would quickly burn out the fine platinum wire.

Burner Orifices. Different types of gas (natural, manufactured, LP) require different orifices. Dryers shipped to areas using a particular type of gas normally have the proper orifice already installed. The wrong orifice will greatly affect the Btu heat input of the burner.

High-Limit Thermostats. The function of the high-limit thermostat is to interrupt the current to the heater if the temperature of the heater housing exceeds a preset limit. In some models, the high-limit thermostat also shuts power to the drive motor so that the dryer must be restarted. This is an extra insurance against overheating. High-limit thermostats are usually preset at the factory, with no field adjustment possible. The high limit is set at about 275°F plus or minus 7°F.

Drum Drive Assemblies. To reduce the 1,725 rpm achieved by the drive motor to the 50 rpm at which the clothes drum must revolve, a speed reduction system is required. One such system uses a motor pulley to rotate the drum with a belt around the entire drum. Earlier models have a belt switch as a safety measure to protect against the dangerous buildup of heat should any of the belts break. This switch is connected in series with the main-burner solenoid, thus shutting off the supply of gas. The same protection is now afforded by the high-limit thermostat used in later models.

Door Switches. Most dryers have a door switch that shuts off both heat and drive motors when the door is opened. In some models, the service door is also protected the same way.

Germicidal Lamps. Germicidal lamps are used in some dryers because of their germ-killing power. These are usually connected in series with the initiator mechanism.

Lint Filters. These are provided with all dryers. These trap and hold the lint shaken loose from clothes as they are tumbled about in the drum.

Vent Kits. In venting to the outdoors, the dryer should be located near an outside wall through which the vent pipe may be easily led. It is suggested that not more than four right-angle turns be made in the exhaust pipe, which may vary from 3 to 4 inches in diameter, depending on the dryer make and model. This vent is also used to vent exhaust gases from the dryer to the outside, thereby reducing the carbon dioxide in the dryer area or room.

Exercise

1. At what rpm does the dryer drum operate?
2. What does the door switch function as?
3. What is the purpose of a vent on the dryer?
4. What size are dryer motors?
5. What permits the gas to flow to the pilot and the main-burner solenoid valve?
6. What closes the circuit to the main-burner solenoid when the motor has reached about 1,400 rpm?
7. How are timers driven?
8. What is the function of the high-limit thermostat?
9. How are germicidal lamps usually connected?
10. What is the maximum number of right-angle turns for an exhaust pipe?

Objectives: After completing this assignment, you will be able to—

1. identify the different types of gas water heaters;
2. describe the operation of the different types of gas water heaters;
3. explain slow-recovery operations;
4. explain the controls used on gas water heaters; and
5. describe the pilot-thermocouple operation.

L-4

Gas Water Heaters

Manual Gas Water Heaters

Manual gas heaters are not normally used to any great extent today. However, their operation, installation, and connections are described here to help repair persons who may service them. Manual gas water heaters, also called *circulating-tank* or *side-arm heaters*, are of conventional design. The gas burner and accompanying heat coils are mounted on the side of the storage tank.

The manual gas water heater is used mainly because of a relatively low initial cost and operating economy. These tanks, as the name implies, are nonautomatic. They can supply hot water quickly by igniting the gas shortly before the water is needed. Because of this limited service, the operating cost is relatively low. However, if these tanks are used continuously at a rather low temperature setting, much of this economy is lost.

The manual gas water heater is most likely located in a remote part of a building (in the basement of homes, hotels, etc.). Special clocks or timing devices, as well as distant control lighters, are available. Manual gas water heaters are generally equipped with copper coils 17 to 20 feet in length, with an outside diameter of about 1 inch. These coils are usually made of heavy copper tubing because of the liming in hard water.

These heaters usually have between 20,000 and 30,000 Btu capacity, although some models may go as high as 85,000 Btu. The smallest heater can deliver about 20 gallons of hot water per hour. This is generally ample for most homes that would use a conventional 30-gallon heater for storing the hot water.

Manual gas water heaters have given rather poor service, not because of any fault in the heater, but mainly because of the improper method of connecting the water heater to the storage tank. The lack of general good service can be overcome if a few simple installation rules are followed.

All boilers of recent manufacture are provided with taps for hot and cold water connections. Two taps located in the side of the tank 6 inches from the top and bottom accommodate the circulating water connections, which should be made of ¾-inch or larger pipe. The side of the tank near the bottom has a tap for connection to the drain or blowoff, which is used to drain water or sediment from the boiler. Circulation pipes between the heater and tank should be made as free from fittings and bends as possible.

Brass pipe should be used on the hot water circulating line from the heater to the tank, particularly for high temperature circulation. Unions, when required, should be placed as close to the heater as possible on the hot and cold water taps and circulating lines. The arrangement of hot and cold water taps at 6 inches from the top and bottom of the tank permits free circulation, which produces a relatively large volume of stored water without overheating. This arrangement also eliminates short-circuiting of water through the heater and provides ample sediment storage below the circulating line, thereby preventing sediment from entering the heating element.

Manual gas water heaters must be installed in accordance with their listing and the manufacturer's instructions. Unlisted water heaters must be installed with a minimum clearance of 12 inches on all sides, including the rear. Combustible floors under unlisted water heaters must be protected in an approved manner. Gas water heaters must not be installed in bathrooms, bedrooms, or any occupied room that may normally be kept closed. All gas water heaters with an input of 5,000 Btu must be vented or provided with some other means of removing the flue gases to the outside.

Automatic Gas Water Heaters

Automatic gas water heaters are those heaters in which the hot water tank, gas burner, combustion chamber, and necessary insulation are all in a single unit with provisions for an automatic supply of hot water. There are two types of automatic gas water heaters—automatic storage and automatic instantaneous.

The **automatic storage** gas water heater has provisions for water storage. The storage tank sizes vary, depending on the requirements. For single family use, a tank of about 75 gallons capacity is usually sufficient.

The storage tank heating elements and control are usually delivered separately. Installation involves setting the tank, installing the copper tubing heating coil and thermostatic heat control unit in the tank, connecting the hot water supply line, and insulating the unit. With this type of heater, the heat from the gas flame is transmitted to the water by direct conduction through the tank bottom and flue surfaces.

Some heaters have multiple central flues. On other designs, the hot exhaust gases pass between outer surfaces of the tank and the insulating jacket. In either case, these areas become radiating surfaces and dissipate the heat of the stored hot water to the flue or chimney when the burner is off.

The gas *slow-recovery* water heater is designed to keep a constant supply of hot water in the storage tank. It uses a constantly burning gas flame to continuously deliver hot water to this tank. Thermostats are either graduating or snap-action type. With the graduating-type thermostat, the burner operates between a low and high flame. The low position of the flame acts as a pilot to keep the heater lighted and also serves as a source of standby heat. The slow-recovery water heater is extremely economical since it can never burn more than a certain amount of gas, depending on how the thermostat is regulated. The small heating surfaces keep the standby loss at a minimum, thereby making this type of heater advantageous where economy is the primary consideration.

The *quick-recovery* water heater is able to produce hot water at a more rapid rate than the slow-recovery type. It is often used where heavy usage of hot water makes it essential to have enough water available on demand. The thermostats generally used are the throttling or snap-action type. In the throttling-type thermostat, the amount of gas-valve opening is directly proportional to the temperature changes of the water in the tank. In the snap-action type, the change from a completely open to a completely closed valve position, or vice versa, is accomplished by a snap action, which is produced by a clicker diaphragm motivated by the temperature of the water in the water heater tank.

The difference between the slow-recovery and the quick-recovery water heaters is the amount of gas consumed by each unit. For example, a quick-recovery heater with a 25,000 Btu input can deliver 23 gallons of hot water per hour indefinitely. However, a slow-recovery heater can never burn more than a relatively low and predetermined quantity of gas, with an accompanying reduction in hot water delivery.

Automatic instantaneous gas water heaters differ from the other types mainly in that they do not store any heated water. They heat the water directly on demand. Instantaneous water heaters are actuated by flow valves or water motors that actuate the gas flame whenever water is drawn from the faucet. Gas burners for this type of service are usually built up from several parts, with a hood to protect the burner from condensation and to direct and hold the flames. In addition, burners are usually equipped with a gauge to protect the flame from backflash.

Since instantaneous water heaters operate by a water motor or flow valve, they have burners with flames that go up and down rapidly. Therefore, a careful pilot adjustment is necessary to ensure effective burner ignition without extinguishing the pilot flame. On this type of heater, the safety pilot flame must be adjusted so that the flames heat the element enough to keep the valve wide open. For proper functioning, a pressure difference of about 15 psi in the water piping is necessary to hold the flow valve or water motor wide open. The Btu input to the heater can be checked with water flowing freely from a sufficient number of faucets to keep the water temperature down and the thermostat wide open. This ensures a wide-open position of the flow valve.

Pilot-Thermocouple Operation

The function of the pilot in a gas water heater is twofold, to ignite the burner and to heat the thermocouple. The purpose of the thermocouple, in turn, is to supply a low-voltage electric current to the magnet in a safety switch, valve, or thermostat. The operation of the pilot-thermocouple combination is essentially as follows:

When two dissimilar metals are tightly fastened together, and heat is applied to one end, an electric current is produced. The thermocouple, usually made of an iron-nickel combination, is bonded together at one end to form a "hot" junction. Two leads are then attached to a coil that is wound around an iron core. When the pilot heats the thermocouple, an electric current is produced. This current energizes the coil on the core, and produces a miniature magnet.

Thermostat Relation

When the thermostat button or dial is actuated, the magnet is pushed forward and engages a safety catch. The safety catch is then drawn back when the button or dial is released. The spring-loaded safety catch snaps back in position if the pilot-thermocouple combination does not produce enough current to create the necessary magnetic holding power.

When the safety catch is in the "off" position, pressure is applied against the main valve. The main valve then closes and stops the flow of gas to the main burner. When the safety catch is held away from the main valve, the valve will open and close as the element tube in the tank contacts and expands in proportion to the temperature changes of the water. This allows gas to flow to the main burner.

The automatic hot water heater is one of the most troublefree home appliances when properly installed. A heater may arrive from the manufacturer in perfect condition, but if certain initial installation procedures are not followed, or if other minor functions are not performed, the heater will not operate satisfactorily.

Exercise

1. Why have manual gas water heaters given rather poor service?
2. Name the two types of automatic gas water heaters.
3. Where are quick-recovery gas water heaters often used?
4. Why is the slow-recovery water heater extremely economical?
5. How do automatic instantaneous gas water heaters differ from the other types?
6. What is the function of the pilot in a gas water heater?
7. Why is a careful pilot adjustment necessary?
8. What happens when the pilot heats the thermocouple?
9. What takes place when two dissimilar metals are tightly fastened together and heat is applied to one end?

Glossary

AC-DC—refers to an electrical device that operates on either alternating current or direct current.

AC generator—a generator that is the source of alternating current.

alligator clip—a clamp-type temporary wire connector.

alternating current (AC)—electrical current in which the electrons move first in one direction and then in the other.

ammeter—a meter used to measure current in amperes.

ampere (amp)—the flow of electrons or current based on one coulomb per second past a point in a circuit.

appliance ground—a conductor leading from the chassis or cabinet of an appliance to a solid ground connection. It prevents the appliance user from receiving a shock in case a component short-circuits. The fuse will blow first.

armature—the rotor of a motor or generator; the actuating plunger or movable core, as in a solenoid or relay.

bimetal—two dissimilar metals with different rates of expansion bonded together. When heated, the assembly will buckle or bend. It is mostly used in temperature-actuated switches to make and break contact points.

British thermal unit (Btu)—the heat required to raise the temperature of one pound of water one degree Fahrenheit.

busbar—a solid wire or bar for making a common connection.

calibrate—to adjust to a known standard or norm.

chassis—the frame or baseplate to which appliance components are attached.

choke coil—a high-inductance coil that prevents the passage of pulsating currents but allows direct currents to pass.

circuit—the path of an electrical current. It is completed when a voltage source is connected by wires or conductors to a load or a resistance.

circuit breaker—a safety switch that acts as a fuse and automatically opens an overloaded circuit. It protects conductors from carrying too much current. Unlike a fuse, it can be reset by pressing a button or resetting the switch lever.

closed circuit—a circuit that is complete and allows current to flow.

condenser—another name for *capacitor.*

conductance—measured in mhos, it is the ability of a circuit to conduct electricity.

conductivity—the opposite of resistivity, it is the ability to conduct electricity.

conductor—any material with the ability to permit passage of electric current.

contacts—the points in a switch where circuits are made and broken.

continuity—the description of a complete circuit in which current can flow.

coulomb—the standard electrical unit of quantity measure, equal to 6.3 billion billion electrons. One ampere is a flow of one coulomb per second.

current—flow of electrons through a conductor, measured in amperes. Its symbol is *I*.

cycle—one complete reversal of an alternating current from positive to negative and back to the starting point.

de-energize—to disconnect a component or circuit from the power source.

dielectric heating—a process of heating by the application of an alternating-current field. The heating is the result of molecular friction.

direct current (DC)—current in which the electrons flow in one direction.

eddy currents—induced currents flowing in a rotating core.

eddy-current loss—heat loss resulting from eddy currents flowing through the resistance of the core.

effective resistance—the ratio between the true power absorbed in a circuit and the square of the effective current flowing in a circuit.

efficiency—the ratio between the output power and the input power.

electromagnet—a coil of wire wound on a soft core of iron. Current applied to the coil causes the core to be magnetized.

electromotive force (emf)—the force with which free electrons move in a conductor, measured in volts.

element—substances either singly or in a combination with other elements from all matter contained in the universe.

energy—the capability of performing work.

factor of safety—a design load, usually above the normal operating load of a circuit, component, or device, that can be handled without damage or hazard.

farad—the measurement unit of capacitance.

field magnets—electromagnets in the field of a generator or motor.

foot-pound—the measurement of energy or work. It is the energy used to move one pound of material a distance of one foot.

frequency—the measurement of complete cycles per second of alternating current.

full-load voltage—the source voltage available when full-load current is being drawn.

fuse—a protective device placed in series with each building circuit. It contains a fusible link or wire that will melt and break the circuit if current draw reaches an unsafe level or value.

generator—a device for converting mechanical energy into electrical energy. A rotor containing conductors is mechanically rotated in magnetic fields, causing voltage to be induced in the conductors.

gilbert—a unit of measurement of magnetomotive force.

ground—the common current return for a complete circuit to the power source. The final connection is to the earth with rods or plates. For example, the compressor shell is connected by a green wire to the cabinet. The cabinet is grounded by the third wire to the third prong of the service cord. The third prong is grounded to earth through the house circuit in a properly installed system.

ground wire—a conductor connected to a ground rod, water pipe, etc., on one end and attached to a receptacle box or appliance on the other.

heat loss—energy loss due to the resistance of a conductor or a coil.

heat sink—a mass of metal attached to a component to draw heat away and assist in dissipating the heat to ambient air or material.

henry—the unit of measurement of inductance.

horsepower—one horsepower equals 746 watts, 33,000 foot-pounds per minute, or 550 foot-pounds of work per second.

impedance—the total opposition to flow of an alternating current resulting from resistance and reactance.

induced current—the current flow caused by an induced voltage.

induced voltage—the voltage induced in a conductor or coil as it moves through a magnetic field.

inductance—the opposition to a change in current in an electric circuit; the storage of energy in a magnetic field of a circuit.

joule—a unit of energy equal to one watt-second.

jumper—a length of wire or a conductor [illegible] to make temporary connections, such as a bypass around a switching component.

kilo—prefix meaning one thousand times.

law of magnetism—like poles repel each other, and unlike poles attract each other.

load—a power-consuming device or component that contains resistance.

loss—the dissipation of energy without accomplishing useful work.

master switch—a switch that controls the operations of, or the circuit to, several other switches.
mega—prefix meaning one million times.
meter—an instrument or device for measuring quantities of electricity.
mho—the unit of measurement of conductance.
micro—prefix meaning one millionth of.
micromicro—prefix meaning one millionth of one millionth of.
milli—prefix meaning one thousandth of.
motor—the opposite of a generator, it converts electrical energy to mechanical energy.
multimeter—a combination meter for reading volts, amperes, and ohms.
negative—the point with the greatest electron concentration.
neon—an inert gas.
nichrome—an alloy of nickel and chromium; a high-resistance wire used for heating elements.
ohm—the unit of measurement of the resistance to flow of current through a conductor.
ohmmeter—a meter for measuring resistance in ohms.
Ohm's law—the mathematical relationship between amperage, voltage, and resistance; $E = IR$, $R = E/I$, and $I = E/R$.
open circuit—broken circuit or load removed so that resistance equals infinity, and no current can flow.
overload—a greater load on a component or circuit than it was designed to carry.
picofarad—the same as a *micromicrofarad*.
polarity—having a definite positive or negative sign.
polarized circuit—the use of a white or marked wire for the ground side of a circuit.
power—the rate of doing work. Electrically, it is measured in watts.
power loss—loss in a circuit due to resistance of conductors.
relay—a magnetic switch. The magnet that operates the switch contacts is activated by a coil. The coil circuit is energized or de-energized by voltage or current passing through it.
resistance—the opposition (or friction) of a conductor to the flow of current, measured in ohms.
resistor—a component offering resistance to the flow of electric current.
schematic—a line drawing of an electric circuit showing components and connections in the form of symbols.
solenoid—an electromagnetic coil for operating an armature or a valve plunger.
switch—a mechanical device for opening or closing a circuit.
terminal—a point of electrical connection.
thermistor—a semiconductor that changes conductivity or resistance when it changes temperature.
thermocouple—a junction point where two dissimilar metals are welded together. Heating the junction generates a small DC voltage. It is used on temperature meters and on gas pilot safety valves.
timer—a clock-motor-operated switching device for stopping and starting electric components at specific time intervals.
torque—the force that produces a twisting or rotating motion.
volt—the unit of measurement of electromotive force or potential difference.
watt—the unit of power measurement.
watt-hour—the unit of energy measurement equal to one watt per hour.
wattmeter—a meter for measuring power in watts consumed by connected loads.